VALTION MAATALOUSKOETOIMINNAN JULKAISUJA N:o 147
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SELOSTUS: *TUTKIMUKSIA KIVENNÄISMAAN SEKOITUKSEN VAIKUTUKSESTA SUOVILJELYKSEN LÄMPÖOLOIHIN*

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Preface

The present investigation has been carried out in the years 1951—1955 as part of the program of the Frost Research Station at Pelsonsuo.

I wish to acknowledge the deep gratitude I owe to the Head of the Central Meteorologic Institute, Professor MATTI FRANSSILA, Ph.D., for the guidance which I have received from him in the course of this work. He has also read through this manuscript and aided its completion with numerous valuable comments. To Professor JAAKKO KERÄNEN, Ph.D., I am similarly highly indebted for his valuable advice.

My esteemed teacher, Professor ERKKI KIVINEN, D. of Agriculture and Forestry, acquainted himself with my work at an early stage and has given generous advice, particularly with regard to the arrangement of the material for publication, for which I wish to express my sincere thanks. I also wish to thank Dr. TANELI JUUSELA, D. Techn., for valuable advice and comments on the manuscript. Besides, I want to thank him for valuable literature.

I have particular reason to be grateful to Mr. ULJAS ATTILA, M.Sc., who has designed and built equipment for my investigations. He has also translated this work into English and made many apposite suggestions, especially concerning to the technical description of the temperature measuring device, for which my best thanks are due to him.

For linguistic revision of the manuscript my thanks are due to Mrs. JEAN MARGARET PERTTUNEN.

Pelsonsuo, October 1955

Yrjö Pessi.

Contents

Introduction

The admixture of mineral soil with the soil of reclaimed peat land is a measure generally recommended and also fairly widely employed in soil improvement both when peat soils are first taken into agricultural use and in their continued cultivation. The changes in the peat wrought by this procedure are primarily of a physical and chemical character. As the nutrients required by crops can nowadays be given profitably in the form of artificial fertilizers, the main reason for recommending the addition of mineral soil is its influence upon the physical properties of the soil.

A variety of physical changes can be said to arise from the addition of mineral soil. However, in recommending the addition of mineral constituents as a soil-improving measure, stress is chiefly laid on the fact that the thermal conditions of such peat land will become more favourable for cultivated plants. It is well known that, in the Finnish environment cultivated peat land affords less favourable conditions with regard to the thriving of plants than mineral soils. In order to give some idea of the phenomena underlying the changes in the thermal conditions caused by the addition of mineral soil, some of the factors influencing the thermal conditions will be considered in the following.

The main source of heat for the soil layer nearest to the earth's surface consists of the short wave radiation from the sun and sky. Part of this radiation energy is lost through reflection from the earth's surface. The remainder ist absorbed by the earth's surface. On the other hand, heat is lost from the earth's surface as outgoing radiation. The greater part of this radiation returns back as the back radiation. The difference between the incoming and outgoing radiation is called the net radiation or the radiation balance of the earth's surface. Part of this energy balance is consumed in warming up the upper layers of the soil, another part in warming up the adjacent air and a third part is losed through evaporation. It is thus seen that the thermal conditions of the soil depend on the size of the radiation balance and on the way in which the radiation energy expressed by its numerical value is distributed among and consumed by the various soil layers.

The reflecting number of the earth's surface is called its albedo. In the case of a surface bare of plants, the albedo depends among other things on

the soil quality, the moisture content of the soil and its colour. According to ÅNGSTRÖM (1925) the albedo decreases with increasing moisture content of the earth's surface. A dark surface similarly has a smaller albedo than a surface of light colour. Another factor influencing the radiation balance is the outgoing radiation from the earth's surface; such radiation takes place at all times of the day and night. The outgoing radiation is dependent on the temperature of the earth's surface, increasing with increasing temperature. It has been established that the earth's surface radiates virtually as an absolutely black body; consequently it is possible to calculate the outgoing radiation of the earth's surface with fairly high accuracy with the aid of the STEFAN-BOLTZMANN formula.

During the day a considerable amount of the net radiation is consumed in heat up the upper soil layers. Thus in the daytime there exists a thermal flow towards the deeper soil layers. At the time of negative radiation balance, during the night, a flow of heat in the opposite direction obtains. The rate at which heat is conducted from one soil layer to another will depend, among other things, on the thermal conductivity of the soil. The rapidity of this heat transfer is directly proportional to the thermal conductivity, and there are great differences between the various soil types in this respect. As a rule mineral soils possess a considerably higher thermal conductivity than peat soils. Air having a very poor thermal conductivity in comparison with any kind of soil and with water, the soil possesses a lower thermal conductivity if it contains more air. Light soil is thus of lower thermal conductivity than heavy soil and a similar relation exists between dry soil and wet soil.

The amount of evaporation is dependent on the temperature, the moisture of the earth's surface and the humidity of the air, and on the wind velocity. It is obvious that the evaporation of water from a wet soil surface is higher than from a dry surface. Evaporation mainly takes place in the daytime, as the requisite amount of heat is often absent in the night. Indeed, in the night the opposite phenomenon frequently occurs, i. e., the condensation of water vapour in the form of dew or hoarfrost.

Peat soils and mineral soils differ in regard to such properties as their thermal conductivity, specific heat, colour, volume weight, and moisture condition. Consequently the addition of mineral soil to the soil of cultivated peat land causes changes in the albedo of its surface, in the thermal conductivity of the soil, its specific heat, its total porosity and its moisture condition, among other things. As it is known, moreover, that the quality of the underlying soil may also affect the microclimatie, it can be concluded that the admixture of mineral soil will produce changes both in the thermal conditions of the soil and in the layer of air next to the ground. Although these facts have been recognized previously, no full understanding has been

reached the extent of the changes brought about by the addition of mineral soil. In Finland the only investigations relating to this subject are those of KARSTEN (1917) and VESIKIVI (1933), which cannot be said to settle the question completely.

The present work deals with investigations made in the years 1951—1955 at Pelsonsuo, with the object of ascertaining the effect of the addition of various quantities of mineral soil on the thermal condition of cultivated, reclaimed peat land. Investigations have been made with one type of peat only and with only one kind of mineral soil as a soil-improving agent. This restriction was made with a view to studying the influence of varying quantities of mineral soil, it being considered more important to institute a comparison in this respect than to compare the effect of different kinds of mineral soil, since the use of mineral soil as a soil-improving agent is a procedure frequently involving considerable expenditure, on account of which the farmer will have to give careful consideration to the amount of mineral soil to be added to the peat. In this investigation the chief emphasis was laid upon comparisons of the changes in the thermal conditions of the peat land caused by the admixture of mineral soil.

Attention was also paid to the minimum temperatures in the layer of air next to the ground, which are of great practical importance from the standpoint of the frost phenomenon.

Elsewhere, this question has been studied specially in Germany and in Sweden (FLEISCHER 1891, WOLLNY 1891, FEILITZEN 1902, 1912 b, KREUTZ 1943, BRÜNE 1948, BADEN 1952). There are, however, features which render it difficult to interpret these earlier results with a view to practical application and owing to which the said results can only be accepted with reserve. It may be mentioned as one of the factors impeding the interpretation of the results that the quantities of mineral soil employed are not always stated in the investigations (FLEISCHER 1891). In VESIKIVI's investigations the vegetation was removed from the test plots, for which reason the conditions were not comparable with those encountered in practice. Furthermore his series of measurements were rather short.

It has to be considered a factor detracting from the reliability of the results of numerous earlier investigations that no replications have been used in the measurements and that the measurements have been performed with the aid of liquid-in-glass thermometers. The suitability of such thermometers for accurate measurements of soil temperatures is to be considered dubious (KÜHL 1907, p. 17—23, KERÄNEN 1920, p. 5).

FLEISCHER (1891) has carried out temperature measurements in Germany on a test plot mixed with sand and on one covered with sand. The quantities of mineral soil employed are not stated. He found that throughout the year the mean value of the temperature at 11 cm depth was 0.5°C higher

on the test plot mixed with sand, and 1.0 C higher on that covered with sand, than on an unsanded plot, the corresponding figures relating to the summer-time being 1.5 and 3.0 C (p. 831—833). At a depth of 28 cm the differences were smaller, according to the same author, but still similar in direction (p. 844—845). At 60 cm depth he only performed measurements on the unsanded and the sand-covered plots, finding temperature differences of identical direction even at this depth (p. 850). His measurements do not reveal any noteworthy regularity with regard to possible variations in the differences between the different months of the summer.

In South Sweden, FEILITZEN (1902, 1912b) performed temperature measurements once a week with one and the same thermometer, which was moved from one point of observation to another. His experiment comprised three plots, one of which was not sanded, while the second had 250 m³ of sand per hectare admixed with its cultivated layer and the third plot was covered with 1 000 m³ of sand per hectare. With oats as experimental plant, the mean temperature between 29. V and 5. X at 20 cm depth was 1.3 C higher on the sand-covered plot than on the unsanded plot. With oats and vetch as experimental plants the differences between sanded and unsanded plots were of the same order of magnitude. In a pasture land 5 years of age admixture of sand increased the said mean temperature of the summer-time by 0.7°C according to his observations (1902, p. 144—145). FEILITZEN's (1912 b, p. 7) results also reveal that the temperature differences were highest in the spring and early summer. This is also evident from the investigations of WOLLNY (1891).

KARSTEN (1917) carried out investigations at Tikkurila on several days in the second half of September. The test plots were about 2 m², one being untreated, whereas the second was admixed with clay in an amount of 400 m³/ha and the third with sand at 400 m³/ha. Measurements were made by KARSTEN every hours with the aid of liquid-in-glass thermometers at depths of 1, 10 and 20 cm. The temperature was 0.3—0.5°C higher on the plots admixed with sand and clay than on the plot without mineral soil addition. He has also calculated the thermal conductivity and the heat exchange on the various test plots.

VESIKIVI (1933) has made observations on the soil temperatures at Leteensuo in connection with certain experiments on the admixture of clay and sand. In 1928 he performed measurements on three plots, one of which was untreated, whereas the second was admixed with clay in an amount of 400 m³/ha and the third with sand at 400 m³/ha. These amounts of clay and sand were applied twice: once in the year 1910 and once again in 1928. Measurements were made by VESIKIVI at depths of 2, 10 and 20 cm at 7, 15 and 21 hrs. on several days in the first half of September. The mean values of the observed temperatures differed from each other in that

the sanded soil and the soil admixed with clay were warmer at 10 cm depth than the plot without mineral addition by 0.3 and 0.2°C respectively, the corresponding differences at 20 cm depth being 0.1 and 0.2°C.

Furthermore, Vesikivi (1933) carried out temperature measurements in connection with an experiment of 25 years' standing on the effect addition of clay. The addition of clay had been 100 and 400 m^3/ha, in two instances respectively. In 1929 the temperature observations of June to August displayed such differences that the temperature at 10 and 20 cm depth on the plots admixed with clay was at the most 0.6°C higher than on the plot without addition of clay.

Kreutz (1943) made observations on the soil temperatures in Germany on several days in June, 1939, in connection with certain experiments on the admixture of sand. Measurements were made by Kreutz at depths of 5, 10 and 20 cm on three plots, one being admixed with sand in an amount of 500 m^3/ha, the second 1 000 m^3/ha and the third 1 500 m^3/ha. He found that the greater the quantity of sand admixed, the warmer the soil became in the daytime and the higher were the minimum temperatures.

This question was also studied in Germany in 1951—1952 (Baden 1952). Observations on the soil temperatures were made with the aid of liquid-in-glass thermometer on the soil surface and at depths of 5, 10, 20 and 50 cm. The quantities of mineral soil employed were 1 000—1 500 m^3/ha sand. In the summer-time the monthly mean temperatures were higher on the plots mixed with sand. The temperature differences were nearly similar at every depth. The greatest differences in the mean temperatures of the summer months were about 3°C (Baden 1952, p. 91). During the winter months the inverse differences apply.

De Vries (1954) has made observations in Holland and calculated theoretically that about 1 000—1 300 m^3 sand/ha changes the soil temperature conditions to correspond with those of mineral soil.

Investigations on the effect of the addition of mineral soil upon the temperature of the layer of air next to the ground are few. Feilitzen (1912 a) has studied this question with the aid of measurements of the minimum temperature at 10 cm height from a soil surface from which the plant cover had been removed over a circular area of 1 m diameter. The mean values of the minimum temperatures show almost identical differences throughout the months of May to September. The results should, however, be considered with reserve, since the author himself states that the sanded plot was possibly more unfavourable with regard to its location than the other plots. Indeed the minimum temperatures over the plot admixed with sand were on the average lower by 0.2—0.5°C than those over the unsanded plot and those of the sand-covered plot were about 1°C higher than those of the unsanded plot.

Kreutz (1943) also studied this question with the aid of measurements of the minimum temperature made at 10 cm height above the soil surface on several days in June, 1939. He found that the addition of mineral soil caused an increase in the minimum temperature of the layer of air next to the ground. This is also evident from the investigations at Bremen (Baden 1952, p. 184).

I. Experimental area and weather conditions

1. *Experimental area, lay-out of the test plots and their treatment*

The investigations were carried out during the years 1951—1955 at Pelsonsuo ($\lambda = 26.5° E$, $\varphi = 64.3° N$). The site of the investigation was part of a bog area of about 14 000 ha, about 7 000 hectare of which are suitable for cultivation. So far about 1 500 ha of the bog have been reclaimed for cultivation.

Up to 30. VII. 1952 the object of investigation was an improvement test, which had been established on newly reclaimed land in the following way. The peat layer had a depth of 60 cm on an average, the peat being poorly humified sedge peat. The subsoil was fine sand (table 1). The field was drained by open ditches 90 cm in depth, which divided the land into strips 20 m wide, as measured from centre to centre of the ditches. Sand was used as a soil improver (table 1). The depth of the cultivated layer was

Table 1. Mechanical composition (see method, Saveri 1952) and pH of the fine sand soil used as a soil improving agent and of the sub-soil, determined by the Viljavuuspalvelu Company, Ltd.

	Soil	Percentage of fraction				pH
		0.6—0.2 mm	0.2—0.06	0.06—0.02	0.02—0.002	
Soil improving agent in the first test	Fine sand	—	91	4	5	5.5
Sub-soils and soil improving agent in the second test	»	1	95	3	1	5.5

about 30 cm. The test plots were successive squares of 100 m², situated in the middle of one strip of land. The treatments consisted of the admixture of 0, 200, 400 and 800 m³ of mineral soil per hectare, respectively. No replications were made. The mineral soil was spread over the test plots in the spring of 1951; after this each test plot was harrowed three times and

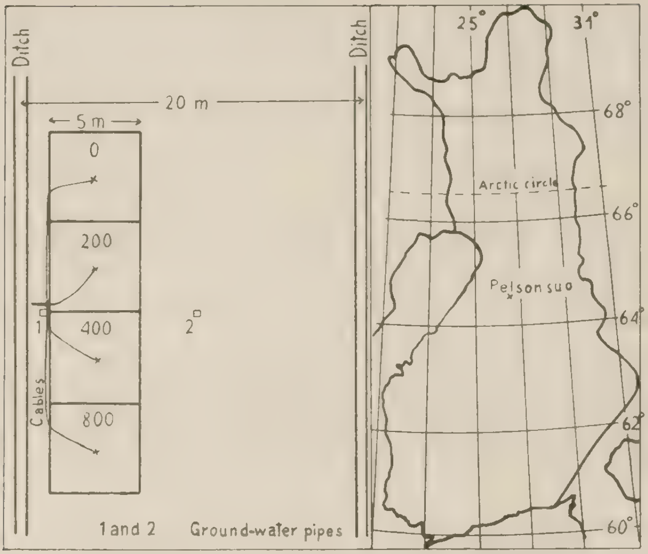

Fig. 1. Map showing location of the Frost Research Station and of the test plots and ground-water pipes in connection with the soil improvement test established in 1952.

sown with oats. In the spring of 1952 the area was harrowed again and sown with oats. No ploughing was performed in the meantime. The measuring thermocouples were inserted in the soil on 16. VI. 1952, at depths of 5, 10, 20 and 30 cm.

During the period 9. IX. 1952—27. IX. 1954, investigations were carried out in connection with another experiment on soil improvement, which was similarly established on newly reclaimed land. The draining system was the same as in connection with the first area. The average depth of the peat layer was 156 cm, the peat from the surface to 100 cm depth consisting of poorly humified sedge peat and from 100 to 156 cm of moderately humified brown-moss peat. The basal soil and the mineral soil used as a soil-improving agent were the same as in the first test (table 1). The test plots were squares of 25 m^2, and the test comprised the same treatments as the first one. The location of the test plots is shown in fig. 1. No replications were made. The mineral soil was spread over the test plots in the dry state on 15. VII. 1952 and mixed with the cultivated layer with the aid of hoe and spade to a depth of about 20 cm. The depth of the first ploughing on the strip of land in question was about 30 cm. An attempt was made to remove as far as possible all non-humified residues of plants, mainly the hair-moss (*Polytrichum commune*), from the cultivated layer.

Table 2. Vegetation in the experiments relating to soil improving agents. Test plant: oats.

Test plot	Test started in 1951						Test started in 1952		
	1951			1952			1953		
	Tiller-ing	Den-sity	Cut	Tiller-ing	Den-sity	Cut	Tiller-ing	Den-sity	Cut
0	15. VI	10	11. IX	8. VI	10	15. IX	13. VI	8	16. IX
200, 400, 800	10. VI	10	11. IX	5. VI	10	15. IX	12. VI	8	16. IX

The measuring thermocouples were inserted in the soil on 8. IX. 1952, at depths of 5, 10, 20, 50 and 100 cm. In the spring of 1953 the area was sown with oats. In the summer of 1954 the soil surface was kept bare of plant cover.

In the following, the test plots will be denoted 0, 200, 400 and 800, referring to the amount of mineral soil, m^3/ha, used on each plot.

Table 2 gives some data on the vegetation in connection with the tests on soil improvement. The tillering has been estimated by eye and that day has been recorded as the date of tillering on which tillering has been assumed to be complete. At this stage the soil surface already begins to appear distinctly green. The density has been assessed according to a scale of 0—10, 10 denoting completely dense plant cover.

On no test plots did the crop lodge during the investigations. In order to avoid lodging, sowing in the spring of 1953 was done with a smaller quantity of seed than usual, this having been proved by experiments made at the research station to be a valuable precaution.

In the spring of 1954 the stubble from the crop of the preceding year was scrupulously eradicated and the soil surface smoothed out.

2. *Weather conditions*

The general features of the weather conditions during the period of the temperature measurements in the years of the investigation are seen from table 3, which gives the deviation of the monthly mean temperatures and of the rainfall from the normal values, as well as the corresponding figures for the entire year and for the period May to August. Figs. 9 and 10 on page 30 illustrate the snow-cover conditions on the site of investigation. Furthermore, table 27 (p. 71) reveals the frequency of spring frosts at night in the bog area.

Table 3. Temperature and rainfall, as measured at a meteorological station at Pelsonsuo 1 km away from the test area. The normal values have been calculated from the years 1901—1930. During this time the wheather has become warmer (KERÄNEN 1952).

Month	Temperature, °C				Rainfall, mm				Number of rainy days		
	Normal value	Departure from normal 1952	Departure from normal 1953	Departure from normal 1954	Normal value	Departure from normal 1952	Departure from normal 1953	Departure from normal 1954	1952	1953	1954
January	—10.3	+4.1	+0.1	+0.5	40	— 5	—10	— 6	21	16	14
February ...	—11.0	+4.2	—4.5	—6.8	32	+19	— 2	—30	22	14	4
March	— 6.8	—4.9	+2.5	+3.8	30	— 9	— 5	— 9	12	11	18
April	— 0.3	+1.2	+2.8	+0.1	34	—17	— 1	—29	9	12	4
May	5.9	—0.9	+0.1	+3.9	42	— 3	—11	—22	11	14	6
June	11.8	+0.8	+5.4	+0.1	61	—37	— 2	+42	8	15	20
July	15.2	—0.6	—1.0	+2.3	71	— 2	+28	+21	14	17	20
August	12.3	—0.9	+1.6	+1.4	77	—16	+62	—18	13	22	11
September ..	7.2	—1.5	—0.8	+1.5	62	+ 8	—33	+32	14	9	22
October	0.7	—2.8	+2.7	+0.7	63	—58	—31	— 3	7	19	14
November ...	— 4.3	+0.3	+3.0	+1.0	47	—19	—13	—23	14	13	15
December ...	— 8.5	+0.5	+6.3	+6.9	43	— 8	— 7	+31	20	12	22
Year	1.0	—0.1	+1.5	+1.3	602	—69	—26	—14	165	174	170
May to August	11.3	—0.4	+1.5	+1.9	251	—15	+75	+22	46	68	79

II. Equipment and methods of investigation

1. *Measurement of temperature*

The *soil temperature measurements* were performed with the aid of a multiple-point, direct reading temperature measuring apparatus, using for its primary thermometer elements thermocouples designed and built by Mr. U. Attila, M.Sc. This device combines the two principles of the resistance thermometer and of temperature measurement by means of thermocouples.

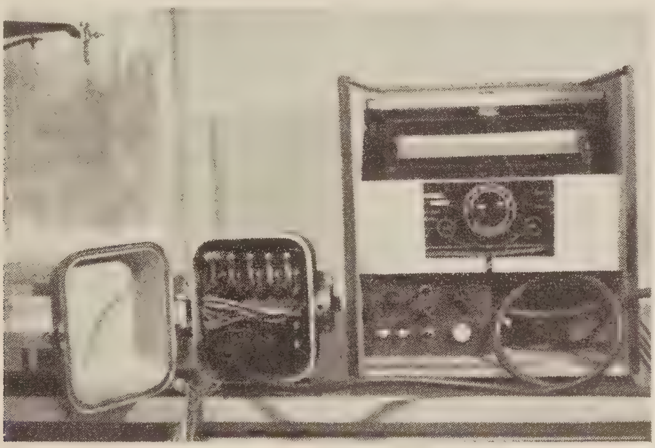

Fig. 2. The portable soil-temperature measuring device and one thermocouple connecting box.

It is well-known that thermoelectric temperature measurements are based on the property of any junction of two conductors of different metals to generate an electromotive force together with a second similar junction with which it is connected in series, but with reversed order of the metals, if a temperature difference exists between the two junctions. The E. M. F. is proportional to this temperature difference within limits of accuracy quite narrow enough for the present investigation. Thus, when the series

connected junctions are connected to the binding posts of a galvanometer of suitable characteristics and appropriate calibration, also considering any resistances in the circuit, including that of the thermocouple junction leads, the temperature difference can be read directly from the galvanometer scale. The thermocouple metals which have been used in the present case are copper vs. constantan (a nickel-copper alloy), which is the commonest combination employed for the measuring of small temperature ranges.

The measuring device used in this work is of a more complicated design than a mere calibrated galvanometer in order to eliminate the necessity of accounting for the temperature of the reference junction, which might be done either by taking the reading of a thermometer in adequate thermal contact with the reference junction and adding this reading to the observed temperature difference, or by keeping the reference junction at 0°C. For this purpose, the reference junction is integrally built together with a resistance thermometer unit, in this case a resistance wound of insulated copper wire. This unit displays a resistance which, within the required limits of accuracy, depends linearly upon its temperature and thus on the temperature of the reference junction. The electrical circuit of the measuring device is such as to produce a galvanometer deflection equivalent to the sum of the reference junction temperature and the temperature difference between thermocouple junction and reference junction, both in °C. Thus the actual temperature of the thermocouple junction appears directly as a galvanometer reading.

The measuring device proper has been made portable and is provided with a flexible cable, which can be plugged in at any one of a number of connecting boxes, each of which can take up the weatherproof lead wire cables from ten thermocouples.

In addition to the galvanometer and a panel containing the electrical circuits and the necessary circuit controls, the wooden case of the measuring device holds a battery of six 1.5 V telephone cells as a current source for the light spot of the galvanometer and a 4.5 V flashlight cell, which is required in the measuring circuit. The flexible cable is stored in a compartment of the case during transport.

The principle diagram of the measuring circuit is shown in fig. 3. The fixed resistors R_1 and R_2 constitute a Wheatstone bridge circuit together with the fixed manganin-wire resistor R_{mang} in the connecting box to which the measuring device is connected and with the copper-wire resistor (resistance thermometer reacting to the reference junction temperature) R_{Cu} in the same connecting box. The galvanometer G lies in the bridge path of this circuit, and the thermocouple and reference junctions (t_x and t_0) together with their lead wires can be considered merely a series resistance to the galvanometer, which also includes the adjustable resistance coil Q.

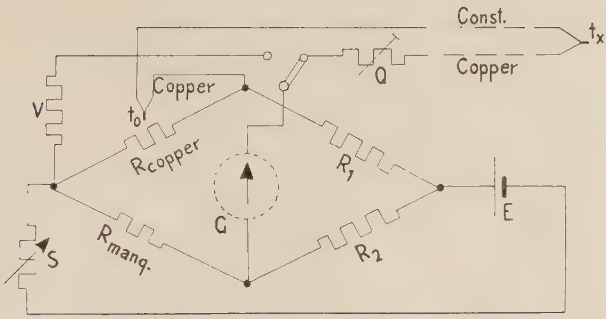

Fig. 3. Diagram illustrating the principle of the thermocouple instrument with automatic reference junction compensation.

This is only strictly true on the assumption that no temperature difference exists between the junctions.

The resistances R_{Cu} and R_{mang} are permanently adjusted in relation to each other so as to produce equilibrium of the bridge, i. e., produce zero current in the galvanometer when the resistor R_{Cu} is at 0°C. If this is not the case, there will be a current through the galvanometer proportional to the temperature of R_{Cu}, in degress C, its direction dependent on whether this temperature is above or below 0°C. The factor of proportionality is dependent on the setting of the adjustable resistor S by which the current through the Wheatstone bridge can be adjusted, independent of the voltage of battery E and the individually slightly different sensitivities of the R_{Cu} resistors, to produce accurate temperature readings. The correct setting of resistor S is obtained when a specified control deflection is obtained with the galvanometer connected to resistance V instead of a thermocouple line. This latter resistance is incorporated in each connecting box and is permanently adjusted in conformity with the R_{Cu} resistance in the same box.

When the thermocouple and reference junctions are at different temperatures, the resulting E. M. F. acts as an independent current source, adding to or subtracting from the galvanometer reading. The dimensioning of the circuit elements is such as to give the same deflection for each degree centigrade, whether it be a change in the temperature difference between the junctions or in the temperature of the reference junction.

A special lead branching off from the flexible cable and terminating in a selector plug permits the connection into the galvanometer circuit of any one of the ten thermocouple junctions and the reference junction resistance unit alone, in addition to its particular position for the checking of the setting of resistor S. Identical sensitivity of the galvanometer in all cases is only achieved if all thermocouple circuits are exactly equal in

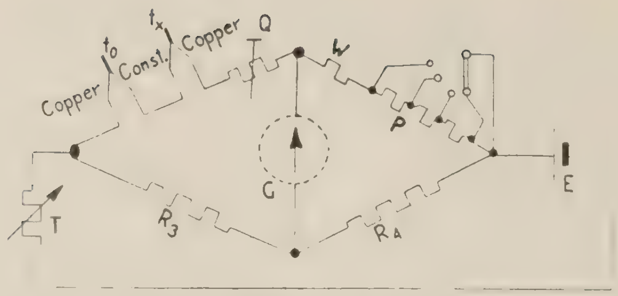

Fig. 4. Diagram illustrating the Wheatstone bridge circuit for the measuring of resistance.

resistance. The coil of resistance wire Q connected in series with each thermocouple makes it possible to adjust their resistances to a common value, even though the lead wires are of different lengths.

For the adjusting of the resistance wire coils part of the measuring circuit can be converted into a Wheatstone bridge for the measuring of resistance, as shown in principle in fig. 4. The resistance wire of the coil has to be shortened until the bridge is in equilibrium. To facilitate this work, a stepped resistor P is connected in series with the standard resistor W of correct resistance, its steps being equivalent to certain lengths of the resistance wire. The device also incorporates a control by which the sensitivity of the galvanometer can be varied during this work.

The resistance of all thermocouple branches was adjusted to 75 ohms with an accuracy corresponding to a change in length of 0.5 cm of the resistance wire in the adjusting coil. The total resistance of the measuring circuit concerned being 150 ohms and that of 0.5 cm of the resistance wire 0.13 ohms, the residual error could amount to 0.9 % at most, corresponding to less than 0.02° C for the temperature span of 20° C covered by the thermocouple measurement.

The entire circuit diagram of the temperature-measuring device is shown in fig. 5.

The thermocouples were made of specially manufactured copper-constantan cable, which at the same time served as lead wire, by twisting together and soldering the bared ends of the two wires. The copper and constantan wire were both of 0.5 mm diameter and were covered with a strong polyvinylchloride insulation. The thermocouple junctions, which were soldered with tin without the use of any flux other than resin, were protected with a ceramic bead and enclosed in copper sockets filled with a cable compound. The sockets were of 27 mm length, 5 mm outer diameter and 0.5 mm wall thickness (fig. 6.).

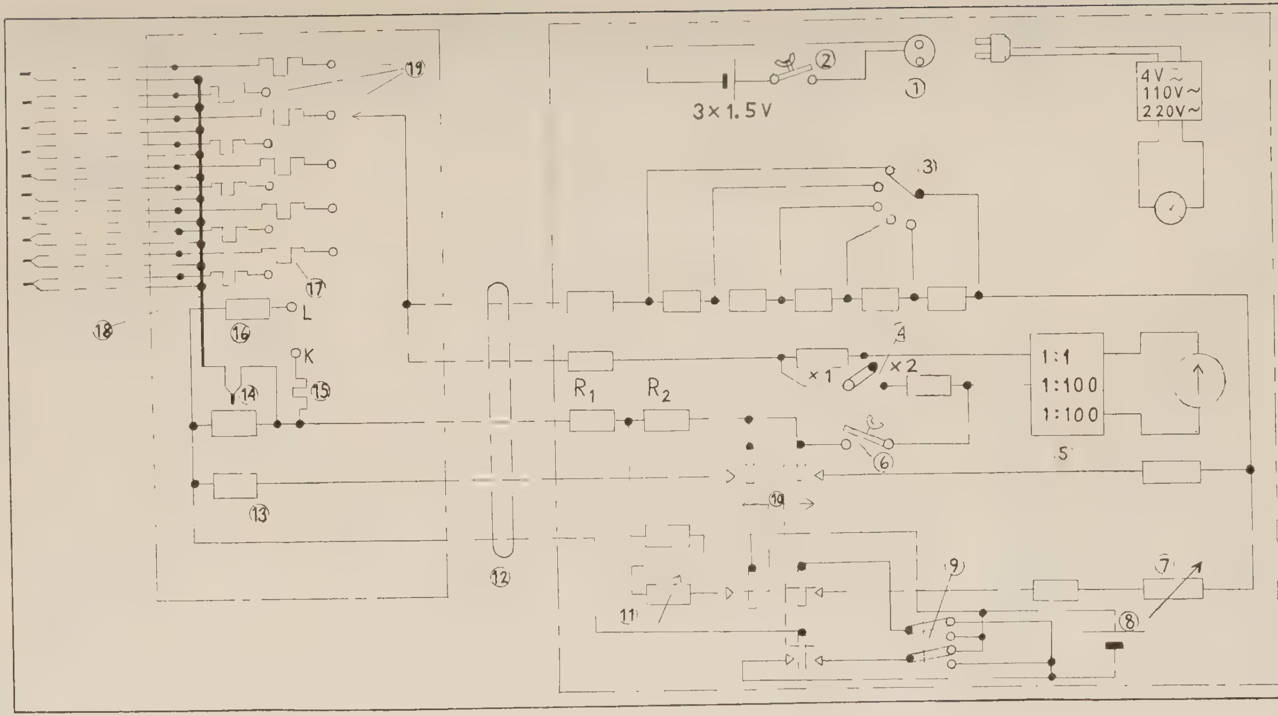

Fig. 5. Circuit diagram of the temperature-measuring device.

1. Plug receptacle
2. Light spot push button
3. Step resistor
4. Scale doubling switch
5. Galvanometer sensitivity switch
6. Galvanometer push button
7. Sensitivity control (resistance check)
8. 4.5 V flashlight battery
9. Pole changer (resistance check)
10. Main switch (Measurement — Off — Resistance check)
11. Current standardization
12. Flexible cable
13.—16. Resistors in the connecting box
17. Equalizing coil
18. Constantan busbar
19. Contact terminal

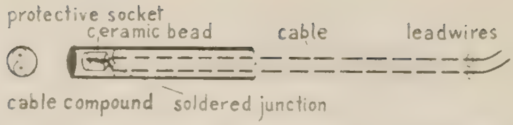

Fig. 6. Longitudinal and cross-section of a thermocouple element (full size).

The galvanometer was a portable light spot galvanometer »Multiflex MG 1« (Dr. *B. Lange*, Germany) of internal resistance 60 ohms and of a sensitivity which yielded a deflection of one scale division (= 1 mm) for a current of $2 \cdot 10^{-8}$ A.

The procedure in temperature measurement with this device was as follows (cf. fig. 5):

The portable case of the measuring device, which includes the galvanometer, is placed in an approximately level position. The plug of the flexible cable is inserted in the receptacle (20) of the connecting box (fig. 7), the water-tight cover of which has been opened for the measurement. The selector plug is connected to terminal K. The galvanometer sensitivity switch is kept in position 1: 1.

With the push button (6) in its neutral position, the light spot is made to fall on a chosen point of the scale by turning the adjusting knobs of the galvanometer and/or shifting its scale strip.

The switch (10) is turned to the left, the button (6) is depressed and the knob of the resistor (11) rotated until the deflection from the zero position is exactly 10 cm. This procedure standardizes the auxiliary current in the bridge circuit to its correct value. The selector plug is then connected to the terminal of each point of measurement in turn and the temperature reading is obtained when the button (6) is depressed. If the temperature is so high or so low as to make the light spot travel beyond the scale limits even when the original zero setting has been made to coincide with either scale margin, the temperature span corresponding to the entire scale width can be doubled by throwing the switch (4).

The fairly weak luminosity of the light spot of the galvanometer employed made it necessary to turn the galvanometer scale towards the shadow and even to make use of a black cloth in bright sunshine.

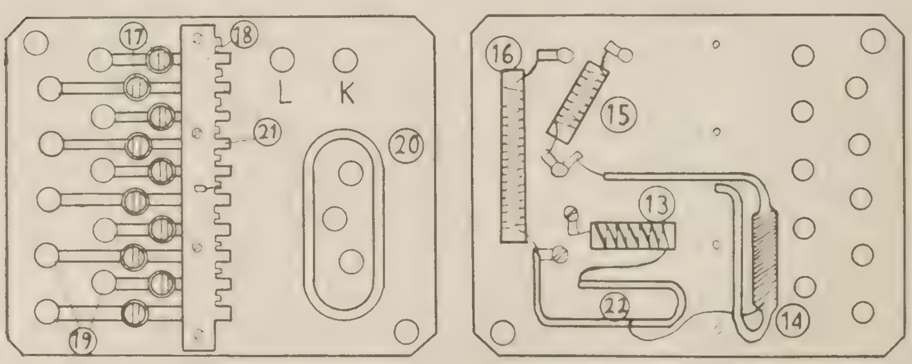

Fig. 7. Front and rear view of the panel in the connecting box.

After installation of the connecting boxes and thermocouples it was found that their accuracy was not entirely up to expectation. The temperature readings were found to be dependent on the temperature of the reference junction, in a way individual for each connecting box. Mostly the readings were correct at approximately + 10°C in the connecting box; at higher temperatures in the box a certain deduction and at lower temperatures an addition would have been required. This defect was due to inadvertent errors in the adjustment of the connecting box circuits, caused by the inadequacy of the calibrating equipment which could be procured at the time in question, only shortly after the war. It has since been shown that the errors could be rectified, but it was not considered worth while to attempt adjustments of the box circuits since they could not be brought to the laboratory without excavating the thermocouples.

One method of eliminating these errors would have been to tabulate empirical corrections in terms of the box temperature and the thermocouple readings, but it was found very satisfactory to proceed as follows. One measuring element of each box was left free so that it could be immersed in a thermos flask with a calibrated thermometer (*Assmann* psychrometer thermometer of *R. Fuess*, graduation 1/5°C) before the series of measurements with this box. The auxiliary current was then adjusted to render the same temperature reading as the calibrated thermometer, when the selector plug was connected to this element. It can be shown mathematically that this results in faultless temperature readings when the thermocouples are at the temperature according to which the auxiliary current was set. Accordingly the temperature in the thermos flask was chosen to approximate to the expected temperatures. In some cases the fault could not be rectified with the aid of the auxiliary current, which was obviously due to an exhausted battery, and recourse was taken to the use of corrections until the battery could be replaced. These corrections seldom exceeded 1°C.

It should be pointed out that although this inadvertent defect of the measuring apparatus made it lose, in this particular investigation, the advantage that no thermos flask would be needed for the reference junction or other purposes, it still retains the originally desired feature that the temperatures measured are read directly in degress C from the galvanometer scale, without any need to observe and add any reference temperature, which may always introduce errors that are difficult to rectify afterwards.

Great care was required in many respects in order to ensure reliable observations of the relatively high degree of accuracy desired.

The galvanometer of high sensitivity, which was chosen as being the most suitable type available at the time and also in view of its ready adaptability to other subsidiary measurements, was comparatively susceptible to external vibration. For this reason the portable instrument case was always placed on a special stand consisting of boards fitted on a heap of heavy stones and separated from the observer. This support was found to be adequate in calm weather, whereas a special windshield had to be used in the case of strong wind. The successive measurements of the various elements connected to one terminal box involving only the shifting of the selector plug from one terminal to another without any need to touch the controls of the instrument panel, its galvanometer button being kept in the locked position, no change of the galvanometer zero due to external shock was experienced. The circuit was designed so as to obtain critical damping of the galvanometer in every case. Consequently the light spot moved rapidly to its final reading without overshooting or oscillation.

The resistance of the thermocouple circuits was checked from time to time, which was also useful in revealing possible breaks in the circuit. A further check was carried out in the case of each element whenever its temperature reading was close to 0°C. Whenever breaks in the circuit were established and the time of their occurrence could not be ascertained, the readings of the element in question from the time of the latest positive check were disregarded. Once this was necessary in the summer of 1952. No changes in the resistance of the thermocouple circuits necessitating a repeated adjustment and inquiry into their cause were observed during this investigation.

The use of switches and other mechanical contacts in circuits operating on such minute thermoelectric forces always introduces the possibility of errors. Almost in the initial stage of the measurements it was found necessary to replace the multiple switch (10, fig. 5) in the instrument panel on account of unreliable operation. Even later it was found advisable to keep an eye on its operation. The periodic cleaning of its silver contacts with fine emery paper and a piece of cardboard wetted with alcohol was generally sufficient to restore its satisfactory operation. No faults were observed in the other switches. The bushings in the connecting plug of the flexible cable widened in the course of time, as was evident from a fluctuation of the galvanometer deflection when the plug was moved to and fro, and they had to be shrunk in this case. This condition was always checked before the commencement of measurements with each box. The selector plug was always put into place with a slight rotation.

In order to check on the occurrence of contact trouble during one series of measurements, the temperature of one thermocouple kept at constant temperature was read before and after the other measurements. No other readings were repeated if these two readings were identical.

The comparison of the reading from one thermocouple with the indication of the thermometer in the thermos flask, which was mentioned before, was also useful with a view to detecting other possible sources of error.

The calibration of the galvanometer circuit was such as to give a deflection of 1 mm for 0.1°C, the entire scale width corresponding to a span of 20°C. If the temperature was above +20°C or below —20°C, the value of one scale division was doubled by throwing the appropriate switch in the instrument panel; thus 0.2°C gave a deflection of 1 mm and the measurements could be extended down to —40°C and up to +40°C.

All the soil temperature observations included in this work were made by the author personally.

The *measurements of air temperature* were carried out with the aid of maximum and minimum thermometers of *R. Fuess*. The maximum thermometers were provided with a *Budig* radiation shield of diameter 7 cm. In connection with the minimum thermometers a cylindrical shield was used, of 7 cm length and 3 cm diameter. It is true that the use of this radiation shield results in too low values and lower values than with the use of the *Budig* shield (Pessi 1954), but this circumstance has no significance in regard to the present investigation, which only concerns the comparison of temperatures.

2. *Measurement of radiation balance*

The radiation balance was measured with the aid of a net radiation instrument developed by Suomi, Franssila and Islitzer (Franssila 1953, Suomi 1954). The instrument was compared in May, 1954, with a Michelson bimetal actinometer. In the present experiment, the instrument was directly connected to the terminals of the light spot galvanometer belonging to the temperature measuring device. A deflection of 1 mm was thus equivalent to 0.0035 cal/cm² · min. At a radiation balance in excess of 0.7 cal/cm² · min it was necessary to throw the switch (4, fig. 5) in the instrument panel of the temperature-measuring device into the scale-doubling position, giving a sensitivity of 1 mm per 0.007 cal/cm² · min.

With a view to easier transportation of the net radiation instrument, the lead wires from the galvanometer and the storage battery to the instrument were made 25 m long. The instrument could thus be moved all over the test area, while the galvanometer and battery remained in one place. The long leads increased the resistance of the fan motor circuit so that a voltage of 10 V was required to obtain satisfactory ventilation.

The absorbing plate of the instrument was placed at about 90 cm height from the soil surface.

The measurements of the different test plots were carried out by moving the instrument, together with its tripod, from one plot to another after each galvanometer reading. The controls of the galvanometer were not touched during a series of measurements, in order to avoid any zero shift due to mechanical shock. In the daytime, the radiation balance was measured, in each series of measurements, four or five times in succession on each plot and the average of the results was recorded for this plot and time of observation. During the night, when the radiation balance is fairly constant (Franssila 1936, p. 88) (fig. 26), only three such consecutive readings were taken from each test plot.

The paint used to blacken the absorbing plate of the instrument has a different absorption for the short wave radiation from the sun and sky (93 %) and for the long wave radiation from the earth's surface (88 %) (Suomi 1954). Since the instrument was calibrated in the daytime, its readings are correct in this respect, whereas too low values are obtained during the night. The corresponding correction were made.

3. *Determination of specific weight, total porosity and moisture content*

The soil samples for the investigations relating to the physical condition of the soil were taken with the aid of a metal cylinder of 46 mm diameter with a slightly constricted orifice. Such samples were taken from the soil layers at 0—10 cm and 10—20 cm depth. The procedure was as follows:

An iron bracket of the shape shown in fig. 8 was pressed horizontally into the soil layer in question from a vertical surface cut with a spade,

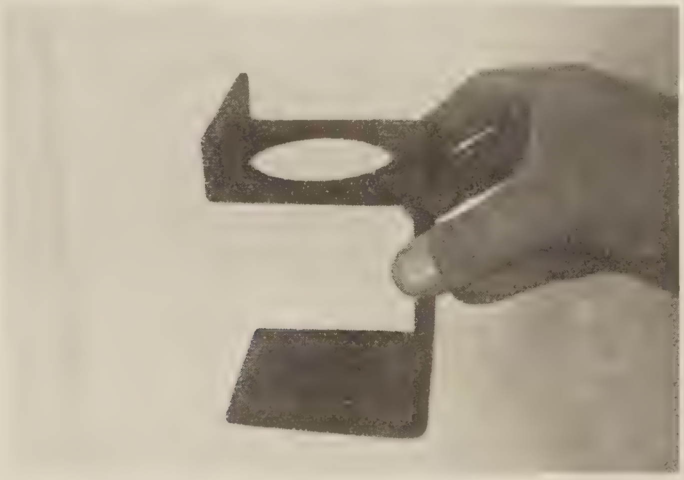

Fig. 8. Bracket used in taking soil samples.

after the superfluous earth above the layer under investigation had been removed or, in the case of the topmost layer, after the soil surface had been smoothed. The above-mentioned sharp-edged cylinder was then thrust in, under continuous rotation, through the circular opening in the bracket, until it met the opposite horizontal metal face. The vertical distance the two sides of the bracket being exactly 10 cm, it was possible to obtain in this way a soil sample of quite accurate volume even from loose soil. Immediately after the samples had been taken, they were weighed with an accuracy of 1 g.

The specific weight of the soil was determined according to the rapid method of Albert and Bogs (1914) (cf. Heinonen 1954). As receptacles checked 50-ml graduated flasks with a narrow neck and a sharp graduation mark were used. The weighed flasks were filled to about $^1/_3$ with ground, air-dried soil and were weighed. Ethyl alcohol was poured into the flask from a 50-ml automatic burette along the glass wall of the flask during about 5 minutes, until the soil sample was well covered with alcohol. The burette was read with an accuracy of 0.01 ml, the last decimal being estimated.

The final filling of the flasks took place at earliest after 24 hours, during which time the flasks remained stoppered and were frequently tapped against a sheet of cork. The flasks were only handled by their necks and they were kept at the same room temperature all the time.

Simultaneously with the determination of the specific weight a determination of the moisture content of the air-dried soil was carried out from another sample, which was kept overnight at 105°C.

In calculating the specific weight, the volume of the water in the air-dried soil was assumed to equal 85 % of the volume of the corresponding free water quantity, in according with the empirical results of HEINONEN (1954, p. 25).

Knowing the volume, specific weight and moisture content of the soil sample, it is possible from these to calculate its total porosity.

4. *Determination of specific heat*

The specific heat of the soil is generally determined in the laboratory from soil samples by calorimetric methods. At the time of this investigation no calorimetric equipment suitable for this purpose was available. For this reason the possibility was studied of calculating the values of the specific heat theoretically for the different test plots. After due consideration this method was adopted.

In making a theoretical calculation of the specific heat the heat capacities of the water, peat, and mineral soil in a given quantity of soil were calculated separately and their sum was divided by their total weight. The quantity of water was known from the determination of the moisture content and the proportion of peat and mineral soil in the sample was ascertained from its specific weight. For this purpose the specific weight of the peat and of the mineral soil as well as of the sample from the test plot in question was determined. The values of the specific heat of peat and mineral soil were obtained from the literature. For dry peat KARSTEN (1917, p. 320) has found the specific heat to be 0.48 cal/g·°C, and for dry sand and dry clay 0.20 and 0.23 cal/g·°C respectively. Consequently in our calculations the dry peat was assumed to have a specific heat of 0.48 and the mineral soil used as a soil-improving agent a specific heat of 0.22 cal/g·°C.

Since the conclusion of these experiments, a calorimetric apparatus specially designed for the determination of the specific heat of such soil samples has become available. In preliminary tests with this device, which showed it to fulfil its purpose very satisfactorily and to yield highly reproducible results, specific heat values in good agreement with those calculated in the above-mentioned way were obtained with comparable soil samples.

III. The investigations and their results

1. *Distance of the ground-water level from the soil surface*

No measurements of the distance of the ground-water level from the soil surface were made during the period 18. VI—30.VII. 1952. Since during this time the test area was situated on a strip of land adjacent to a nearly dry main ditch of 2 m depth, the ground-water could not rise to the levels of the temperature measuring points (see p. 14). During the time 9. IX. 1952—27. IX. 1954, however, such measurements were made simultaneously with the temperature measurements. Ground-water pipes made of boards were placed, one in the middle of the strip and the other at 1 m distance from the feeder ditch in the middle of the test area (fig. 1). The distance of the water level from the soil surface was measured with the aid of a graduated stick, the moment of its contact with the water surface being indicated by ripples in the water. The distance of the ground-water level from the soil surface at the point where the thermocouples were inserted was calculated from the observations at these two points. As the test area was level and the distance between the thermocouples of the test plots most removed from each other was not more than 15 m, it is scarcely probable that the ground-water could differ remarkably in height in the different test plots. Consequently it was not considered necessary to use a greater number of ground-water measuring pipes.

The results of these measurements are given in table 4. It is seen from this table that in 1952 the ground-water level remained below the lowest point of temperature measurement (see p. 15). In 1953, the ground-water level rose in the beginning of April above the level of the two lowest temperature measuring points, sinking below the 50 cm depth on 20.IV and below the 100 cm depth on 9. V. After this date the ground-water did not rise above the 100 cm level until the next year. In 1954 it rose above the 100 cm depth four times, but not once to 50 cm. The first of these four periods was 28. IV—11. V, the second 22. VI—9. VII and the third one occurred in August, when the ground-water level was observed to be above the 100 cm depth on two days of measurement 12. and 18. VIII. The fourth time during the same summer when the ground-water rose above the lowest point of temperature measurement was on the last day of measurement.

Table 4. Distance of the ground water surface from the soil surface at the test area.

Date	Distance, cm	Date	Distance, cm	Date	Distance, cm
9. IX —52	102	17. V—53	117	6. V —54 ..	78
22. IX	125	21. V	128	14. V	115
29. IX	131	25. V	129	19. V	145
2. X	133	2. VI	149	22. V	>156
5. X	137	5. VI	155	22. VI	70
10. X	146	7. VI	>156	26. VI	64
16. X	148	2. VIII	156	30. VI	70
19. X	150	10. VIII	120	6. VII	82
23. X	156	12. VIII	119	8. VII	91
27. X	>156	18. VIII	130	15. VII	144
20. III —53	126	22. VIII	131	21. VII	>156
7. IV	24	28. VIII	130	12. VIII	95
16. IV	38	1. IX	132	18. VIII	68
20. IV	50	6. IX	141	23. VIII	109
25. IV	60	16. IX	145	26. VIII	121
29. IV	64	24. IX	150	2. IX	>156
5. V	87	29. IX	>156	27. IX	56
11. V	107	28. IX —54 ..	72		

2. *Snow-cover*

During the winters, observations were made concerning the depth and density of the snow-cover. In order to determine the snow depth, graduated sticks were placed in the middle of the test plots, close to the thermocouples, in the autumn. The density of the snow-cover was determined from samples taken outside the test area, using the snow balance designed by KORHONEN and MELANDER (KORHONEN 1922). Three parallel determinations were made in each instance.

The depth of the snow-cover is seen from fig. 9 and its density from fig. 10. It is seen that in the two winter periods the snow was of approximately the same depth on all the test plots during the first half-month. After this the depth of the snow-cover begins to vary. The greatest differences in the depth of the snow occur in the second half of February 1954, when the snow depth on test plot 800 was at times only 58 % of that on test plot 200.

The values of the snow density represented in fig. 10 might be somewhat different if they had indeed been measured on the test plots. At least it can be said that they do not represent the actual density of the snow-cover of all test plots, since the snow depth on these was different. It is well-known that the snow-cover usually displays layers of different kinds which differ in density. This has also been established in both the winters studied in the present investigation. In spite of these facts the figure affords some idea of the way in which the density of the snow-cover varies during the winter.

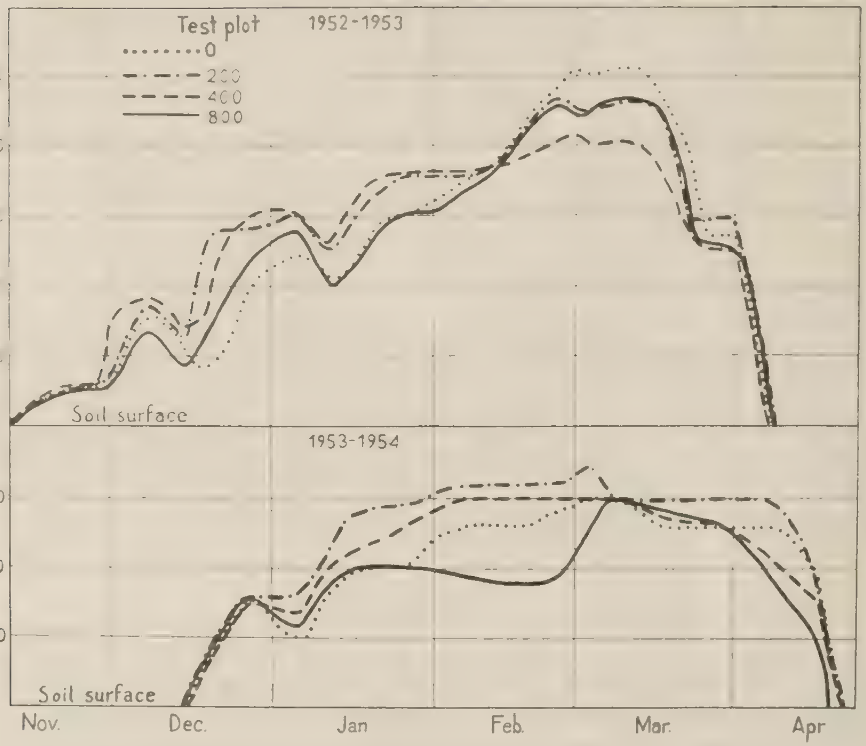

Fig. 9. Depth of the snow-cover during the winters of 1952—53 and 1953—54.

The observations of both winters show that the density of the snow is lowest in the early winter. It increases slowly in the course of time, reaching its maximum in the spring at the melting of the snow. It is further seen that the density of the snow was higher throughout the winter of 1952—53 than at corresponding times in the winter of 1953—54. In the spring of 1953 the snow had melted away on 7. IV. in 1954 on 24. IV. In the latter case the snow disappeared from test plot 800 three days earlier than from the other plots. The recorded date of meltnig of the snow is the day on which the point of insertion of the thermocouples has become free on each test plot.

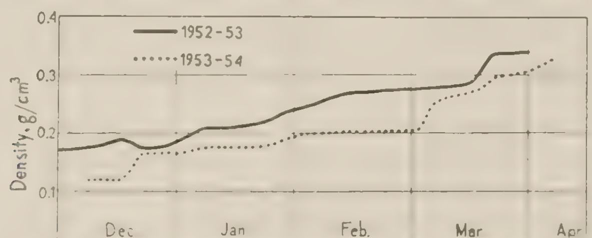

Fig. 10 Density of the snow during the winters of 1952—53 and 1953—54.

3. *The insertion of the thermocouples in the soil*

In inserting the thermocouples in the soil the following points were observed (cf. JUUSELA 1945, p. 114—116):

— The structure of the soil should be changed as little as possible,
— Good thermal contact should be established between measuring element and soil,
— The formation of water-conducting channels should be avoided as far as possible,
— Thermal conduction between different vertical soil layers along the thermocouple leadwires should be minimized as far as possible.

With all these objects in mind it was considered best to insert the thermocouples, not vertically, but horizontally into soil undisturbed by excavating. For this purpose a hole of about 60 cm depth and 22.5 by 30 cm in area was dug out with a spade. A wooden device similar to a carpenter's square was placed in this pit with one leg along its vertical wall and the other leg parallel to the soil surface. Holes were then punched in the vertical wall with a steel rod equal in diameter with the protecting socket of the thermocouples, the rod being guided by horizontal grooves of appropriate size in the vertical leg of the square. In this way horizontal channels varying in length between 15 and 25 cm were produced, their distant ends retaining with reasonable accuracy the spacing and depth from the soil surface of the guiding grooves. Each thermocouple was then inserted in its hole and finally pushed even somewhat further with the aid of a thin steel wire pushing against the rim of the metal socket, in order to establish a good thermal contact between the element and the surrounding soil. All thermocouples down to that at 50 cm depth were installed in this way. Only the thermocouple at 100 cm depth was inserted vertically from the bottom of the pit. Finally a painstaking attempt was made to restore the removed earth in the original succession of its layers in the pit.

As was mentioned above, the horizontal installation of the measuring elements was made with the particular object of avoiding the flow of rain water along its leadwires to the measuring point. For the same reason a downward bend was made in each leadwire on filling up the pit. Obviously the horizontal installation also satisfies the condition that the least possible heat flow should occur along the leadwires to or from the point of measurement, as in this way a consideable stretch of the leadwire of each thermocouple will be at an approximately constant temperature.

The placing of the thermocouples was partly determined by the lengths of the ready-made thermocouple leadwires, although other aspects could

also be taken into account. All the thermocouples of test plot 0 were chosen so as to be connected to the same terminal box, as it was intended to retain this point of investigation intact for other investigations even after the conclusion of the present experiments. As a rule an endeavour was made to place the thermocouples from any box in one and the same test plot.

It has already been mentioned that the investigations were made in connection with two soil improvement experiments. The original intention being to start the long-term investigations in the autumn of 1952 when adequate equipment was to have been completed, preliminary studies were carried out before this time with less extensive equipment to assist in the planning of the later investigations. Such questions were, among others, the choice of suitable depths at which the thermocouples should be placed, the advisability of having replications, and the question as to how frequent observations are required to reveal the essential temperature differences between the test plots.

In connection with the first test the thermal conditions in the soil were studied on the test plots 0, 400 and 800. The thermocouples were placed at depths of 5, 10, 20 and 30 cm, without replicates. The depths of the thermocouples were not checked on removal.

In connection with the second soil improvement test the thermal conditions in the soil were studied both on the above mentioned plots and also on the test plot 200.

Since the daily temperature variations in the different test plots appeared to extend to depths around 20 cm, the thermocouples at 30 cm were later omitted. As it appeared likely, however, that the annual temperature differences would be appreciable even at greater depths, thermocouples at 50 and 100 cm depth were added. This also necessitated the establishing of the second soil improvement test, since the peat layer only had an average depth of 60 cm in the first test.

It was further established by means of sample tests in connection with the first experiment that it was advisable to use at least two replicates at each level measured down to 20 cm. On the other hand, the following of the temperature at the soil surface was abandoned during the snow-free months, since the sample tests revealed that this would have necessitated the use of several replicates and continuous care with regard to the location of the thermocouples. Two thermocouples each were thus placed at 5, 10 and 20 cm depth and only one thermocouple at 50 cm and at 100 cm in each test plot.

In the cases in which the temperature of the soil surface was measured, the copper socket of the thermocouple and about 5 cm of its lead wire were placed on the surface of the soil, covered by a soil layer of about 1 mm (cf. Wild 1879, pp. 33—35, Leyst 1890, pp. 185—200). Two replicates were used.

Table 5. Depth of the thermocouples on 29. IX. 1954.

Depth 9. IX. 1952		Depth of thermocouples on 29. IX. 1954		
		I	II	Average
5 cm	200	4.7	4.5	4.6
	400	5.0	4.5	4.8
	800	4.5	3.5	4.0
10 cm	200	9.3	9.5	9.4
	400	10.0	7.5	8.8
	800	9.0	8.2	8.6
20 cm	200	18.5	18.5	18.5
	400	18.0	18.6	18.3
	800	18.5	18.5	18.5
50 cm	200	46.5	—	—
	400	47.5	—	—
	800	47.0	—	—
100 cm	200	95.5	—	—
	400	94.0	—	—
	800	94.0	—	

The extent to which the placing of the thermocouples at the intended depths was successful is seen from table 5, which shows the actual depths of the thermocouples according to an investigation made after the conclusion of the studies on 27. IX. 1954. As the control plot was left intact for other investigations, no information is available as to their ultimate position here, but the accuracy of their placing can be judged from the results for the other plots.

It is seen from table 5 that on 29. IX. 1954 all elements were at a lower depth than intended. The main reason for this phenomenon is probably the settling of the earth during the two years; it should be kept in mind that this was newly reclaimed land. On the other hand, it will be noticed that the settling of the cultivated layer has been of relatively small magnitude. At least in part this can be ascribed to the fact that the thermocouples were not inserted in the test plots until three weeks after the spreading and mixing of the mineral soil (p. 15) and that this intermediate period was very rainy (total rainfall 80 mm, highest rainfall in one stretch 20 mm) compression of the soil resulting.

In the comparison of the depths of the thermocouples particular attention may be called to the fact that the average depths of the thermocouples intended to be placed at 20 cm are practically identical in the different test plots.

In the following, the depths of the thermocouples will be referred to as 5, 10, 20, 50 and 100 cm, regardless of the fact that the exact depths changed during the investigation.

4. *Soil temperature*

a. Significance of the observations

Assuming that the sources of error inherent in the measuring technique, discussed on page 31, have been successfully eliminated to the required degree, there are primarily two factors determining the extent to which the reading of a thermometer embedded in the earth represents the average soil temperature at a given depth. These factors are, first, how exactly it has been possible to place the measuring element at the intended depth and, secondly, to what degree the structure of the soil is unhomogeneous so as to affect the significance of the measurements.

Fig. 11 shows the temperature differences between the replicates on a few days during the growing season at 8 and 20 hrs., these observation times having been used for the calculation of the daily mean temperatures throughout nearly the whole summer (see table 8). It is seen from the figure that at 5 cm depth the temperature differences between the duplicate measurements are approximately equal in all test plots, the greatest difference being nearly 1.5°C. In test plot 0 and test plot 400 deviations of about the same order of magnitude are present at 10 cm depth, whereas the temperature differences between the replicates are below 1°C in the other two plots. The differences between the replicates at 20 cm depth are fairly small in all test plots, even the greatest differences being less than 0.5°C. The temperature values at this depth can indeed be considered very adequately representative of the physical quantity which is the aim of this investigation.

Since the actual depths of insertion of the thermocouples on three test plots were determined at the conclusion of this investigation (table 5), it is possible to study in the case of these plots the degree to which the differences between the replicates in one and the same plot are due, on the one hand to errors in the depth of insertion and, on the other to inhomogeneity of the soil. In this consideration it will be assumed that the depths of insertion of the thermocouples have remained unchanged during the later part of the investigations. Table 6 has been compiled for this purpose, giving the actual temperature differences between the replicates at 14 hrs. on the days of observation in July, 1954. The table also contains the calculated temperature differences which would be expected on account of the difference in depth of the thermocouples in question. The July observations taken at 14 hrs. have been chosen for the reason that the temperature differences between the replicates attain fairly high values in these cases.

It can be seen from the table that the said differences in the test plots 200 and 800 are not in any noteworthy degree attributable to inhomogeneity

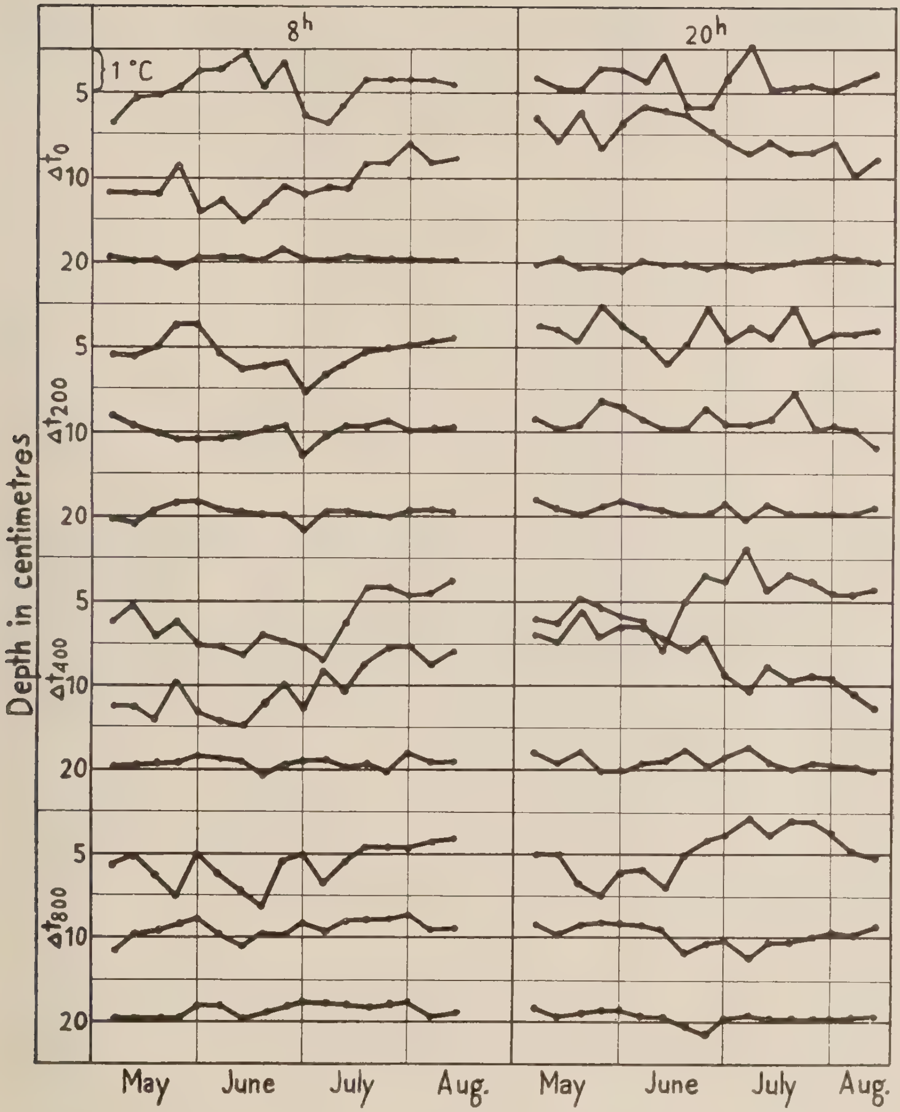

Fig. 11. Temperature differences between the replicates at 8 and 20 hrs. on the days of observation of some months of the growing season in 1954.

of the soil, since the observed temperature differences and those calculated as described above are not essentially different. On the other hand, the differences between the multiples at 5 and 10 cm depth in test plot 400 are largely due to the inhomogeneity of the soil. At 5 cm depth the inhomo-

Table 6. Actual average temperature differences, and differences calculated on the basis of the differences in depth, C, between the replicates at 14 hrs. on the days of observation in July, 1954.

Depth, cm	Test plot	t_1-t_2 at 14.00 hrs. Actual	Calculated on the basis of the diff. in depth
5	200	0.1	0.1
	400	1.0	0.2
	800	0.6	0.7
10	200	0.2	0.1
	400	2.2	0.7
	800	0.4	0.5
20	200	0.3	0.0
	400	0.0	0.2
	800	0.2	0.0

geneity of the soil accounts for about 80 % and at 10 cm depth for about 68 % of the difference. Regarding the difference between the replicates at 20 cm depth, inhomogeneity is of very small account even in this test plot.

Table 7 contains the results of a calculation showing the error which the deviation of 1 cm in the depth of insertion of the thermocouples (table 5) may have introduced in the mean temperature differences between test plots in the months of June to August, 1954.

It may be considered a weakness that the actual depths of the thermocouples in test plot 0 were not checked. It is, however, possible to judge them on the basis of the corresponding results relating to the other test plots; indeed, one may say with considerable certainty that the deviations in the depth of insertion of the thermocouples have no essential effect upon the results of measurement.[1])

Table 7. Error of the monthly mean temperature differences, in May to August, 1954, caused by 1 cm difference in depth of the thermocouples.

Depth, cm	Error, °C			
	V	VI	VII	VIII
5	0.4	0.2	0.1	0.1
10	0.3	0.2	0.1	0.1
20	0.2	0.3	0.1	0.0
50	0.1	0.1	0.1	0.1
100	0.0	0.1	0.1	0.1

[1] The depths of the thermocouples in test plot 0 up to a depth of 50 cm were checked in the summer of 1955. The thermocouples were found to have on the whole the same actual depths as those in the other test plots at the conclusion of this investigation.

Although no replicates were used at any depth in the measurements in connection with the first soil improvement test, it should be possible to assess the reliability of even these measurements on the basis of what has been said above.

b. Computation of the daily mean temperatures

The daily times of observation during the period May to September were 8, 14 and 20 hrs. Furthermore, on some days during the growing season series of measurements were performed every hour throughout the 24 hours. The purpose of these series was to study what kind of formula might be used to compute the daily mean temperatures from the observations made at 8, 14 and 20 hrs. Preference was given to a formula which might be used for all test plots with one and the same constant term. A further requirement of the desired formula was that the constant term accommodating the formula should yield the correct values in some test cases and should be as small as possible. The number of days of observation being in any case definitely too small for finding the absolutely best formula for the computation of the mean temperatures, the first-mentioned requirement was given the greater significance, since it was likely that even a few days of observations would indicate whether or not the said accommodation constant shows any regular correlation with the test plot. It should be kept in mind that in this investigation the chief stress lies on the differences in temperature between the different test plots.

The following four formulae for the computation of the daily mean temperatures were tried out:

(A) $t_m = {}^1/_2\ (t_8 + t_{20}) + k_1$

(B) $t_m = {}^1/_3\ (t_8 + t_{14} + t_{20}) + k_2$

(C) $t_m = {}^1/_4\ (t_8 + t_{14} + 2\ t_{20}) + k_3$

(D) $t_m = {}^1/_4\ (2\ t_8 + t_{14} + t_{20}) + k_4$

where t_8, t_{14} and t_{20} denote the temperatures observed at 8, 14 and 20 hrs., respectively.

No regularity was noticed in the case of any one of these formulae with regard to whether different accommodation constants should be used for the different test plots in the computation of the mean temperatures for the 5 cm depth. For this reason the most suitable formulae for the said mean temperatures were formulae A and D, in which accommodation constants no greater than 0.4°C were required (fig. 12 and table 8), whereas the accommodation constant would vary around 1°C in the case of formulae

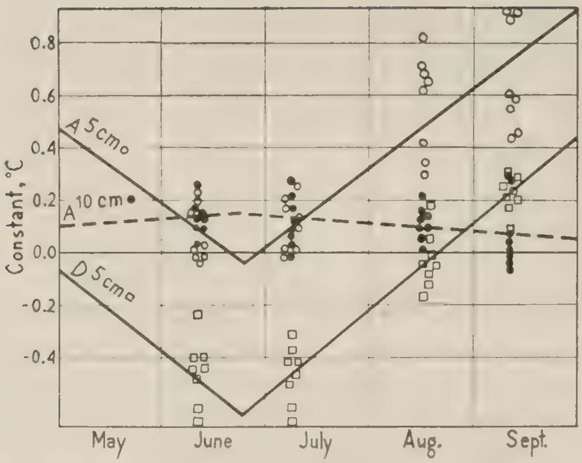

Fig. 12. Accommodation constants required with the different formulae for the calculation of the daily mean temperature.

B and C, being greater than 1°C in the case of formula C throughout the growing season.

For the mean temperatures at 10 cm depth formula A proved to be the most appropriate: it was the only one of these formulae which did not require different accommodation constants for the different test plots. In all cases the constant was 0.1°C (fig. 12 and table 8).

As will be seen later, the daily variations of the temperature at 20 cm depth are of such small magnitude that the corresponding mean temperatures could have been computed without the accommodation constant with the aid of any one of the above-mentioned formulae.

Since the variation of temperature in the winter months is quite slow on account of the snow-cover, the measurements were made only once a day during this period. The same procedure was followed during the month of October and in the second half of April, even though there was no snow-cover. These single daily observations were made at 14 hrs.

The air temperatures at 2 m height are of the meteorological station at Pelsonsuo corresponding the same temperatures than those of the soil.

c. Daily and monthly mean temperatures

Tables 9 and 10 show the mean temperatures observed in the different test plots in connection with the first soil improvement experiment and tables 11 to 20 those obtained in connection with the second experiment.

Table 8. Formulae and accommodation constants employed in the calculation of the daily mean temperatures.

Month	Days	Formula: ± accommodation constant	
		Depth 5 cm	Depth 10 cm
V	1—14 15—31	D − 0.1 A + 0.3	A + 0.1 A + 0.1
VI	1—14 15—30	A + 0.1 A + 0.0	A + 0.1 A + 0.1
VII	1—14 15—31	A + 0.1 A + 0.2	A + 0.1 A + 0.1
VIII	1—14 15—31	D − 0.1 D + 0.0	A + 0.1 A + 0.1
IX	1—14 15—30	D + 0.2 D + 0.4	A + 0.1 A + 0.1

$A = \frac{1}{2}(t_8 + t_{20})$
$D = \frac{1}{4}(2 \times t_8 + t_{14} + t_{20})$

In table 21 the differences between the mean temperatures of the snow-free months (May to September) and that of the entire time of investigation have been compiled, and fig. 13 is a graphical representation of the differences between the monthly mean temperatures of plots 200, 400 and 800 and the mean temperatures of plot 0.

Table 9. Mean temperatures of June, 1952, °C.

Depth, cm	Test plot	Day										Mean
		18.	19.	20.	21.	22.	26.	27.	28.	29.	30.	
Air,	2 m	15.3	18.5	17.5	14.7	13.2	12.8	15.4	20.5	17.7	15.3	—
5	0	13.0	14.6	14.9	13.9	12.8	13.4	13.9	14.7	15.0	16.1	14.3
	400	13.5	15.5	16.1	14.5	13.5	13.8	14.6	15.7	16.0	17.0	15.0
	800	14.8	16.6	16.9	16.5	13.4	14.1	15.3	16.5	16.9	17.6	15.9
10	0	11.9	13.5	14.1	13.2	12.6	12.9	13.4	13.9	14.5	15.3	13.5
	400	12.3	14.9	16.0	14.2	13.0	13.5	14.0	15.1	15.7	16.6	14.3
	800	13.9	16.0	16.6	15.6	13.4	14.0	15.1	16.2	17.0	17.4	15.6
20	0	9.7	10.9	11.9	11.2	11.2	11.1	11.4	11.8	12.3	12.8	11.5
	400	10.9	12.9	14.1	13.2	12.6	12.2	12.7	13.6	14.5	15.0	13.2
	800	11.5	13.7	14.9	13.7	13.0	12.8	13.4	14.5	15.4	16.1	13.9
30	0	7.6	8.2	8.8	8.6	8.6	9.1	9.1	9.3	9.6	9.6	8.9
	400	9.0	9.8	11.0	10.8	10.7	10.4	10.4	10.9	11.6	11.8	10.7
	800	9.1	10.2	11.3	11.1	10.8	10.7	10.8	11.3	12.0	12.2	11.0

Table 10. Mean temperatures of July, 1952, °C.

Depth, cm	Test plot	Day 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	21.	23.	30.	Mean
Air,	2 m	15.4	15.9	15.3	12.1	12.8	15.2	17.8	19.2	22.1	22.4	20.6	20.7	16.6	13.4	11.1	13.8	13.2	16.3	—
5	0	14.4	14.2	13.8	13.3	12.3	12.6	13.9	14.3	14.0	14.5	14.3	14.8	15.0	13.1	14.4	14.2	13.0	12.3	13.8
	400	14.4	14.7	14.6	13.0	12.7	13.4	14.8	15.7	16.6	17.3	18.0	18.2	18.3	14.7	15.9	15.6	14.7	13.5	15.4
	800	15.7	15.3	14.8	13.5	13.6	14.5	15.4	16.4	17.5	18.2	18.7	18.7	19.0	15.0	15.9	16.3	15.6	13.8	16.0
10	0	14.0	14.2	13.6	13.2	13.2	13.3	13.8	14.1	14.5	14.5	15.0	15.2	15.1	13.3	13.9	13.6	13.3	12.1	13.9
	400	15.0	14.3	13.9	13.4	13.4	14.0	14.7	15.5	16.5	17.4	17.8	17.9	17.9	14.6	14.2	15.0	14.0	13.0	15.2
	800	15.8	14.5	14.2	13.6	13.7	14.4	15.5	16.4	17.5	18.1	18.5	18.5	18.6	15.1	14.3	15.8	14.5	13.4	15.7
20	0	12.5	12.2	12.0	12.1	11.8	11.8	12.0	12.0	12.3	12.3	12.5	12.3	12.4	12.2	11.9	11.8	11.7	11.3	12.1
	400	14.0	13.5	13.1	12.9	12.3	12.3	13.0	13.7	14.4	14.8	15.4	15.5	15.6	14.4	13.7	13.2	13.5	12.6	13.8
	800	14.3	14.1	14.0	13.5	13.2	13.4	14.1	14.8	15.7	16.1	16.6	16.6	16.6	14.7	14.1	13.5	14.0	13.0	14.6
30	0	10.3	9.9	9.8	9.8	9.9	9.9	10.0	9.8	9.8	9.9	9.9	9.9	10.0	10.2	10.0	9.8	9.8	9.8	9.9
	400	12.0	11.6	11.4	11.3	11.0	11.0	11.1	11.1	11.5	11.8	12.2	12.2	12.3	12.3	12.0	11.4	11.3	11.1	11.6
	800	12.5	12.1	12.0	11.9	11.6	11.6	11.7	11.9	12.2	12.6	13.0	13.1	13.2	13.2	12.9	11.8	11.7	11.6	12.3

Table 11. Temperatures of September and October, 1952, °C.

Depth, cm	Test plot	September (mean temp.) 9.	10.	15.	22.	23.	29.	Mean	October 2.	3.	5.	7.	10.	14.	16.	19.	23.	27.	31.	Mean
Air,	2 m	7.7	7.8	1.3	3.1	3.1	5.7	—	—0.4	0.7	—1.4	—2.0	4.3	3.0	—1.5	—3.7	—1.4	—13.0	—8.9	—
5	0	7.4	7.6	5.1	2.8	4.2	6.1	5.6	0.7	0.1	0.3	0.1	0.2	3.1	0.2	—0.7	—0.3	—4.0	—3.7	—0.4
	200	7.2	7.1	4.8	2.6	4.3	5.7	5.3	1.0	0.8	0.8	0.5	0.1	2.4	0.3	—0.3	—0.7	—3.5	—3.4	—0.2
	400	7.5	7.4	5.1	3.0	4.4	6.2	5.6	1.6	1.1	0.9	0.9	0.8	2.6	0.5	0.0	—0.5	—2.5	—2.7	0.3
	800	7.6	7.7	5.0	2.7	4.3	6.3	5.6	1.2	0.6	0.6	0.3	1.3	2.4	0.2	—0.3	—0.7	—3.8	4.0	—0.2
10	0	7.6	6.8	5.0	3.5	4.5	6.7	5.7	2.5	1.9	1.8	1.6	1.2	2.6	1.7	0.7	0.4	—0.5	—1.4	1.1
	200	7.6	7.0	5.1	3.4	4.5	6.7	5.7	2.3	2.0	1.7	1.4	0.9	2.8	1.3	0.7	—0.3	—0.8	—1.9	0.9
	400	7.7	7.1	5.1	3.5	4.4	6.8	5.8	2.6	2.0	1.9	1.5	1.0	1.9	1.3	0.7	—0.1	—0.4	-1.7	1.0
	800	7.7	6.8	4.8	2.9	4.1	7.0	5.6	1.8	1.3	1.2	0.8	1.0	2.0	0.9	0.3	—0.4	—1.6	—2.8	0.4
20	0	7.9	7.6	6.5	5.4	5.3	6.2	6.5	4.5	4.1	3.5	3.3	2.8	3.2	2.9	2.4	1.9	1.3	1.0	2.8
	200	8.1	7.9	6.5	5.2	5.2	6.2	6.5	4.2	3.7	3.3	3.1	2.4	3.0	2.7	2.1	1.2	1.0	0.6	2.5
	400	8.1	7.8	6.5	5.1	5.1	6.2	6.5	4.1	4.0	3.3	2.9	2.2	2.5	2.6	2.0	1.2	1.0	0.5	2.4
	800	8.0	7.5	6.2	4.3	4.7	6.4	6.2	3.2	3.0	2.5	2.0	1.6	2.7	2.1	1.4	0.7	0.6	0.0	1.8
50	0	8.2	8.1	7.4	6.4	6.5	6.2	7.1	6.2	5.8	5.5	5.4	4.9	4.3	4.4	4.2	2.9	3.1	3.0	4.5
	200	8.4	8.3	7.4	6.4	6.5	6.3	7.2	6.2	5.7	5.4	5.2	4.6	4.2	4.3	4.0	3.3	3.3	2.8	4.5
	400	8.3	8.3	7.5	6.4	6.4	6.2	7.2	6.2	6.0	5.5	5.5	4.6	4.2	4.2	4.1	3.6	3.1	2.8	4.5
	800	8.5	8.3	7.5	6.5	6.4	6.3	7.3	6.1	5.8	5.4	5.1	4.2	4.2	4.1	3.9	3.2	3.0	2.4	4.3
100	0	7.2	7.0	6.6	6.3	6.4	6.4	6.7	6.3	6.2	6.2	6.3	6.0	5.6	5.6	5.4	5.0	4.8	4.7	5.6
	200	7.5	7.4	6.8	6.5	6.6	6.4	6.9	6.4	6.3	6.2	6.3	5.9	5.5	5.5	5.3	4.9	5.0	4.5	5.6
	400	7.6	7.5	6.8	6.5	6.6	6.6	6.9	6.5	6.5	6.4	6.3	5.8	5.5	5.5	5.2	4.9	4.9	4.4	5.6
	800	7.7	7.7	7.0	6.6	6.7	6.7	7.1	6.6	6.5	6.4	6.4	5.9	5.6	5.5	5.2	4.8	4.8	4.3	5.6

Table 12. Snow depth and temperatures, °C, of November and December, 1952, and January, 1953.

Depth, cm	Test plot	November 3.	7.	11.	19.	25.	28.	Mean	December 1.	4.	8.	15.	20.	28.	Mean	January 5.	13.	21.	27.	Mean
Air,	2 m	—6.1	—2.9	0.2	—1.3	—1.7	—8.5	—	—5.7	—13.0	—19.1	—0.9	—9.4	0.2	—	—11.3	0.8	—6.7	—15.2	—
Snow	0	—	—	—	4.0	5.0	5.5	—	7.0	12.0	15.0	10.0	8.5	20.0	12.1	24.0	21.0	28.0	30.0	25.8
depth,	200	—	—	—	4.0	5.0	6.5	—	8.5	13.0	17.0	12.0	28.0	28.0	17.8	30.0	25.0	33.0	35.5	30.9
cm	400	—	—	—	5.0	6.0	15.0	—	15.0	17.5	18.0	14.0	20.0	30.5	19.2	30.0	28.0	35.0	36.0	32.3
	800	—	—	—	4.0	5.0	5.5	—	6.5	10.0	13.0	8.5	15.0	24.0	12.8	27.5	20.0	28.0	30.0	26.4
Soil	0	—	—	0.0	—0.9	—1.1	—3.4	—	—3.0	—5.0	—5.2	—1.4	—3.8	—0.4	—3.1	—2.2	—0.8	—0.9	—4.1	—2.0
surface	200	—	—	0.1	—1.0	—1.2	—2.1	—	—2.1	—3.3	—3.8	—1.4	—1.1	—0.5	—2.0	—1.6	—0.8	—0.9	—3.0	—1.6
	400	—	—	0.2	—0.9	—1.1	—1.3	—	—2.1	—2.7	—3.6	—1.1	—1.3	—0.4	—1.9	—1.6	—0.7	—0.9	—3.2	—1.6
	800	—	—	0.1	0.9	1.1	3.2		2.8	4.7	-5.2	-1.2	2.3	0.6	2.8	1.9	0.7	0.8	4.3	1.9
5	0	—3.5	—2.3	—0.2	—0.8	—1.6	—3.1	—1.9	—2.0	—2.7	—3.5	—1.1	—2.0	—0.5	—2.0	—1.5	—0.8	—0.9	—2.8	—1.5
	200	—3.4	—2.0	—0.2	—0.9	—1.6	—1.8	—1.7	—1.3	—1.8	—2.2	—0.9	—0.8	—0.4	—1.2	—1.1	—0.8	—0.9	—1.7	—1.1
	400	—2.9	—1.7	—0.2	—0.8	—1.3	—1.4	—1.4	—1.4	—2.0	—2.0	—0.7	—1.1	—0.5	—1.3	—1.1	—0.8	—0.9	—2.1	—1.2
	800	3.7	-2.3	0.2	0.9	1.9	-3.2	-2.0	-2.1	3.7	-4.3	1.1	1.7	0.4	2.2	1.4	0.9	0.9	3.8	1.8
10	0	2.4	—1.6	—0.3	—0.7	—1.0	—2.0	—1.3	—1.3	1.8	—2.1	0.9	1.4	0.5	1.1	1.1	0.7	0.8	2.1	1.2
	200	—2.5	—1.6	—0.2	—0.7	—1.2	—1.3	—1.3	—0.9	—1.4	—1.6	—0.7	—0.6	—0.3	—0.9	—0.8	—0.7	—0.8	—1.2	—0.9
	400	—2.2	—1.5	—0.2	—0.6	—1.0	—1.1	—1.1	—1.0	—1.3	—1.5	—0.6	—0.7	—0.4	—0.9	—0.8	—0.6	—0.6	—1.6	—0.9
	800	3.0	2.0	—0.2	—0.8	—1.4	—2.5	—1.7	1.7	3.0	—3.5	0.9	0.3	0.4	1.6	1.2	0.8	0.9	3.1	1.5
20	0	0.2	—0.2	—0.1	—0.1	—0.1	—0.4	—0.1	—0.4	—0.6	—0.7	—0.4	—0.5	—0.3	—0.5	—0.4	—0.4	—0.4	—0.8	—0.5
	200	—0.2	—0.4	—0.1	—0.2	—0.4	—0.4	—0.3	—0.4	—0.5	—0.5	—0.3	—0.2	—0.2	—0.4	—0.3	—0.4	—0.4	—0.5	—0.4
	400	—0.2	0.4	0.1	0.2	0.3	0.3	-0.3	0.3	—0.6	—0.5	—0.3	0.2	0.2	0.4	—0.4	—0.4	—0.4	—0.7	0.5
	800	—0.8	—0.8	—0.1	—0.3	—0.5	—1.0	—0.6	0.7	1.4	—1.7	0.6	0.6	—0.3	—0.9	—0.6	0.6	0.6	1.7	0.9
50	0	2.8	2.2	1.9	1.6	1.5	1.4	1.9	1.3	1.3	1.3	1.1	1.0	0.8	1.1	0.7	0.7	0.7	0.6	0.7
	200	2.4	2.0	1.7	1.5	1.3	1.2	1.7	1.2	1.0	1.0	1.0	1.0	0.9	1.0	0.8	0.6	0.6	0.7	0.7
	400	2.4	2.1	1.9	1.5	1.4	1.3	1.8	1.2	1.2	1.3	1.2	1.1	0.9	1.2	0.9	0.8	0.8	0.8	0.8
	800	2.1	1.8	1.6	1.3	1.1	1.1	1.5	1.0	0.6	0.8	0.8	0.8	0.7	0.8	0.6	0.5	0.5	0.4	0.5
100	0	4.6	4.1	3.9	3.5	3.3	3.0	3.7	3.0	3.0	3.0	2.8	2.6	2.3	2.8	2.2	2.1	2.1	1.9	2.1
	200	4.3	4.0	3.7	3.4	3.1	2.9	3.6	2.9	2.7	2.8	2.6	2.5	2.3	2.6	2.3	2.0	2.0	2.0	2.1
	400	4.2	3.9	3.6	3.2	3.0	2.8	3.5	2.8	2.6	2.7	2.6	2.5	2.2	2.6	2.0	2.0	1.9	1.9	2.0
	800	4.1	3.8	3.5	3.1	2.9	2.8	3.4	2.7	2.4	2.6	2.5	2.4	2.0	2.4	1.9	1.9	1.8	1.7	1.8

Table 13. Snow depth and temperatures, °C, of February, March and April, 1953.

Depth, cm	Test plot	February					March					April					
		2.	9.	15.	19.	Mean	6.	13.	20.	31.	Mean	7.	16.	20.	25.	29.	Mean
Air,	2 m	—10.7	—17.7	—17.1	—8.2	—	—1.2	—1.5	2.0	—10.4	—	1.8	3.8	—0.7	7.7	9.5	—
Snow depth, cm	0	32.0	35.0	38.0	42.0	36.8	50.0	51.0	41.0	27.0	42.3	—	—	—	—	—	—
	200	35.5	36.0	38.0	42.0	37.9	45.0	46.0	31.0	30.0	38.0	—	—	—	—		—
	400	36.0	36.5	37.0	38.0	36.9	40.0	40.0	29.0	25.0	33.5	—	—			—	—
	800	30.0	34.0	37.0	41.0	35.5	46.0	47.0	36.0	25.5	38.6	—	—	—	—	—	—
Soil surface	0	—4.2	—5.0	—4.9	—4.6	—4.7	0.1	—0.7	0.0	—1.3	—0.5	—	—	—	—		—
	200	—3.2	—4.1	—4.1	—3.7	—3.8	—0.7	—1.7	0.0	—0.8	—0.8	—	—	—	—	—	—
	400	—3.3	—4.1	—4.0	—3.6	—3.8	—0.2	—1.7	—0.0	—0.7	—0.7	—	—		—		—
	800	—4.4	—4.6	—4.6	—4.5	—4.5	—0.3	—1.4	0.0	—0.7	—0.6	—	—	—	—	—	—
5	0	—3.1	—3.6	—3.7	—3.5	—3.5	—0.2	—0.6	0.0	—0.5	—0.3	0.1	1.4	0.0	1.9	4.7	1.6
	200	—2.0	—2.4	—2.6	—2.5	—2.4	—1.0	—1.5	—0.1	—0.2	—0.7	—0.2	0.8	0.0	1.8	4.0	1.3
	400	—2.4	—2.7	—2.8	—2.7	—2.7	—0.9	—1.2	—0.2	—0.2	—0.6	—0.2	0.6	—0.2	1.6	2.9	0.9
	800	—4.1	—4.6	—4.6	—4.5	—4.5	—1.0	—2.0	—0.1	—0.4	—0.9	—0.2	1.1	0.0	2.4	3.7	1.4
10	0	—2.4	—2.9	—2.9	—2.8	—2.8	—0.3	—0.5	—0.1	—0.1	—0.3	0.0	—0.1	0.2	0.1	0.7	0.2
	200	—1.6	—2.0	—2.1	—2.1	—2.0	—0.6	—1.0	—0.1	—0.1	—0.5	—0.1	—0.1	0.0	0.4	1.9	0.4
	400	—1.9	—2.2	—2.2	—2.2	—2.1	—0.7	—0.9	—0.1	—0.1	—0.5	—0.1	0.0	0.0	1.3	2.1	0.7
	800	—3.5	—3.9	—4.0	—3.9	—3.8	—0.8	—1.5	—0.1	—0.1	—0.6	—0.1	0.4	0.1	1.4	3.9	1.1
20	0	—1.2	—1.6	—1.7	—1.7	—1.6	—0.2	—0.2	—0.1	—0.1	—0.2	—0.1	—0.1	0.0	0.1	0.3	0.0
	200	—0.7	—1.0	—1.1	—1.1	—1.0	—0.4	—0.4	—0.1	—0.1	—0.3	—0.2	—0.1	—0.1	0.0	—0.4	—0.2
	400	—0.9	—1.2	—1.3	—1.3	—1.2	—0.5	—0.5	—0.2	—0.1	—0.3	—0.1	—0.1	—0.1	0.0	0.0	—0.1
	800	—2.2	—2.7	—2.7	—2.7	—2.6	—0.4	—0.7	—0.1	—0.0	—0.3	—0.1	0.1	0.1	0.3	1.2	0.3
50	0	0.6	0.5	0.5	0.4	0.5	0.4	0.3	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.4
	200	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.4	0.4	0.5	0.3	0.4	0.4	0.5	0.3	0.4
	400	0.7	0.6	0.5	0.4	0.6	0.4	0.4	0.4	0.4	0.4	0.5	0.3	0.3	0.3	0.0	0.3
	800	0.3	0.2	0.1	0.0	0.2	—0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	—0.2	0.0
100	0	1.9	1.8	1.7	1.7	1.8	1.6	1.6	1.5	1.4	1.5	1.4	1.3	1.4	1.4	1.3	1.4
	200	1.9	1.9	1.8	1.7	1.8	1.6	1.6	1.5	1.5	1.6	1.3	1.5	1.4	1.4	1.2	1.4
	400	1.8	1.8	1.7	1.6	1.7	1.5	1.5	1.5	1.5	1.5	1.2	0.9	0.9	1.3	1.1	1.1
	800	1.7	1.6	1.4	1.3	1.5	1.2	1.3	1.2	1.3	1.3	1.1	1.1	1.0	1.2	1.0	1.1

Table 14. Mean temperatures of May and June, 1953, °C.

Depth, cm	Test plot	May						June							
		5.	11.	17.	21.	25.	Mean	2.	5.	9.	13.	19.	23.	27.	Mean
Air,	2 m	5.0	4.6	11.5	12.6	3.6	—	17.6	17.0	16.0	20.6	21.3	17.6	16.6	—
5	0	5.0	3.8	9.6	10.8	3.4	6.6	12.4	12.9	13.6	17.6	18.7	18.7	15.8	15.7
	200	4.8	3.5	9.0	10.2	3.3	6.2	12.6	13.1	14.0	18.1	18.7	18.7	16.7	16.0
	400	4.3	3.3	7.9	9.0	3.4	5.6	12.4	12.7	13.6	18.3	18.9	18.5	17.2	16.0
	800	5.3	3.8	9.6	10.9	4.1	6.7	13.5	14.0	14.3	19.8	20.3	18.3	18.2	17.0
10	0	2.5	2.2	5.9	6.2	2.9	4.0	7.0	9.1	9.6	12.8	14.8	15.7	14.2	11.9
	200	3.4	2.9	7.1	7.4	3.0	4.8	8.9	10.9	12.1	15.2	16.5	17.1	15.9	13.8
	400	3.4	2.8	7.2	7.5	3.2	4.8	9.0	10.9	12.2	15.7	17.2	17.4	16.3	14.1
	800	4.3	3.4	8.6	9.0	4.0	5.9	8.1	10.2	13.0	17.1	18.2	18.3	17.5	14.7
20	0	0.0	0.1	0.6	0.7	0.8	0.5	3.1	3.7	4.1	5.7	9.2	11.7	12.0	7.1
	200	0.3	0.5	1.8	2.7	1.6	1.4	6.8	7.3	8.7	10.6	12.7	14.1	14.4	10.7
	400	0.7	0.7	2.0	2.8	1.9	1.6	6.8	7.4	9.1	11.2	13.4	14.8	14.9	11.1
	800	2.6	2.1	5.0	5.8	3.4	3.8	9.0	9.5	10.3	13.3	15.3	16.3	16.4	12.9
50	0	0.3	0.3	0.3	0.4	0.3	0.3	0.4	0.4	0.4	0.8	3.1	5.3	6.8	2.5
	200	0.4	0.5	0.5	0.5	0.4	0.5	1.6	2.0	3.9	5.4	7.6	9.1	9.7	5.6
	400	0.5	0.4	0.4	0.4	0.4	0.4	1.0	1.5	3.6	5.1	7.8	9.3	10.0	5.5
	800	0.2	0.2	0.2	0.2	0.2	0.2	1.0	1.2	3.3	5.2	8.2	10.2	10.7	5.7
100	0	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.8	2.5	2.8	3.3	2.1
	200	1.4	1.4	1.4	1.4	1.3	1.4	1.4	1.4	2.1	3.0	4.6	5.4	5.4	3.3
	400	1.3	1.2	1.2	1.2	1.2	1.2	0.7	0.7	1.7	2.3	4.6	5.4	5.6	3.0
	800	1.2	1.1	1.2	1.1	1.1	1.1	0.5	0.5	1.3	2.0	4.4	5.5	5.8	2.9

Table 15. Mean temperatures of July and August, 1953, °C

Depth, cm	Test plot	July								August						
		1.	4.	11.	15.	22.	23.	28.	Mean	5.	10.	12.	18.	22.	28.	Mean
Air,	2 m	16.5	15.7	12.1	16.2	17.1	17.1	17.1	—	11.3	10.5	14.8	16.5	15.5	12.6	—
5	0	15.8	14.7	15.5	16.1	16.3	16.2	16.9	16.0	16.6	13.5	16.9	16.8	13.9	12.6	15.1
	200	16.7	16.1	16.3	16.7	16.6	16.6	16.8	16.6	16.5	13.5	16.8	16.7	13.6	12.3	14.9
	400	17.3	15.9	16.3	16.3	16.3	16.3	16.9	16.5	16.6	13.6	16.9	16.7	13.8	12.3	15.0
	800	18.3	16.2	17.2	17.7	17.0	17.0	17.4	17.3	16.5	13.4	17.0	16.7	13.8	12.3	15.0
10	0	14.0	13.7	14.2	14.4	14.4	14.4	15.7	14.4	15.4	12.5	15.7	15.6	13.2	12.7	14.2
	200	15.3	15.2	15.3	15.4	15.7	15.7	16.2	15.5	15.7	12.5	16.1	16.0	13.0	12.5	14.4
	400	15.5	15.3	15.4	15.4	15.5	15.5	16.2	15.6	15.9	12.7	16.3	16.1	13.3	12.8	14.6
	800	16.6	16.1	16.3	16.4	16.4	16.4	16.5	16.4	16.1	12.8	16.5	16.3	13.3	12.7	14.7
20	0	12.2	12.3	12.4	12.5	12.6	12.6	12.9	12.5	12.2	12.4	14.1	14.0	13.2	12.7	13.1
	200	13.8	13.7	13.7	13.7	13.7	13.8	14.0	13.8	12.5	12.7	14.7	14.6	13.3	12.8	13.5
	400	14.2	14.2	14.1	14.1	14.0	14.0	14.1	14.2	12.6	12.8	15.1	14.9	13.5	13.0	13.7
	800	15.8	15.4	15.1	15.0	15.0	15.1	15.4	15.3	12.8	12.9	15.7	15.6	13.6	13.1	14.0
50	0	7.5	8.2	9.3	9.7	10.0	10.1	10.3	9.3	10.7	11.0	11.0	11.2	11.4	11.4	11.1
	200	10.2	10.7	10.9	11.0	11.3	11.3	11.3	11.0	11.3	11.4	11.5	11.7	11.9	11.8	11.6
	400	10.4	10.8	11.1	11.3	11.4	11.4	11.3	11.1	11.3	11.5	11.6	11.8	11.9	11.8	11.7
	800	11.3	12.0	12.0	12.0	12.0	11.9	11.8	11.9	11.6	12.0	12.1	12.3	12.4	12.1	12.1
100	0	3.8	4.4	5.9	6.5	7.1	7.1	7.6	6.1	8.2	8.2	8.3	8.6	8.6	8.7	8.4
	200	6.0	6.6	7.4	7.9	8.4	8.4	8.4	7.6	8.5	8.7	8.7	9.0	9.0	9.3	8.9
	400	6.2	6.8	7.6	8.1	8.5	8.5	8.6	7.8	8.9	9.2	9.3	9.4	9.4	9.8	9.4
	800	6.4	7.1	8.0	8.6	8.9	9.0	9.0	8.2	9.1	9.4	9.4	9.6	9.6	9.8	9.5

Table 16. Temperatures of September, October and November, 1953, C.

Depth, cm	Test plot	September (mean temp.)								October					November					
		1.	6.	11.	12.	16.	24.	29.	Mean	3.	11.	28.	30.	Mean	4.	11.	19.	25.	28.	Mean
Air,	2 m	10.5	3.7	5.1	6.3	9.6	1.0	10.0	—	4.9	2.8	7.9	—1.5	—	—0.6	1.1	—1.6	—0.3	3.2	—
5	0	11.6	6.6	8.1	8.1	9.1	2.3	8.9	7.8	6.1	4.2	5.0	1.4	4.2	—0.2	0.5	0.1	—1.2	0.5	—0.1
	200	11.4	6.8	7.7	7.7	8.9	2.0	8.9	7.6	5.9	2.2	3.3	1.7	3.3	—0.6	—0.1	0.1	—1.3	0.6	—0.3
	400	11.4	7.0	7.7	7.7	8.8	2.0	8.8	7.7	6.2	1.7	3.0	1.7	3.2	—0.5	—0.1	0.1	—1.3	0.4	—0.3
	800	11.4	7.0	7.7	7.6	8.7	1.8	8.7	7.6	6.1	2.6	3.2	1.8	3.4	—0.6	—0.1	0.0	—1.3	0.4	—0.3
10	0	11.6	8.2	8.3	8.1	8.5	3.7	4.0	7.5	6.7	3.1	3.7	3.8	4.3	0.6	0.5	0.1	—1.2	0.6	0.1
	200	11.6	8.0	8.2	8.2	8.6	2.9	3.4	7.3	6.6	2.0	3.3	3.3	4.0	0.0	0.0	0.1	—1.1	0.4	—0.1
	400	11.6	7.8	8.1	8.2	8.7	2.6	3.1	7.2	6.5	1.8	3.0	3.0	3.6	0.0	0.0	0.1	—1.1	0.2	—0.1
	800	11.7	7.7	7.9	8.2	8.8	2.4	2.9	7.1	6.5	1.8	3.0	3.0	3.6	—0.1	0.0	0.1	—1.3	0.2	—0.2
20	0	11.7	9.7	8.8	8.8	8.5	6.0	6.2	8.6	7.2	4.1	4.8	4.8	5.2	2.4	1.7	1.0	0.0	0.3	1.1
	200	11.8	9.8	8.8	8.6	8.3	5.4	5.7	8.4	7.1	3.4	4.1	4.2	4.7	1.7	1.1	0.9	—0.3	0.3	0.7
	400	11.9	9.6	8.7	8.5	8.2	5.3	5.5	8.3	7.0	3.1	4.6	4.5	4.8	1.7	0.9	0.8	—0.3	0.3	0.7
	800	12.0	9.2	8.5	8.3	8.2	4.6	4.8	8.0	7.0	2.5	4.6	4.6	4.7	1.1	0.6	0.5	0.5	0.3	0.4
50	0	11.4	10.4	9.5	9.5	9.3	7.8	7.4	9.3	7.2	6.6	5.1	5.0	6.0	4.6	3.9	3.1	2.5	2.6	3.3
	200	11.4	10.6	9.4	9.4	9.2	7.9	7.4	9.3	7.2	6.1	5.2	5.2	5.9	4.2	3.1	2.7	2.3	2.2	2.9
	400	11.5	10.7	9.4	9.4	9.1	7.6	7.3	9.3	7.0	6.1	5.2	5.0	5.8	4.1	3.1	2.7	2.2	2.4	2.9
	800	11.5	10.8	9.3	9.2	8.9	7.4	7.1	9.2	6.8	5.6	5.1	5.0	5.6	3.9	2.8	2.5	2.0	1.8	2.6
100	0	8.8	8.5	8.6	8.6	8.5	7.5	7.3	8.3	7.1	7.0	5.4	5.2	6.2	5.3	5.0	4.4	4.0	4.0	4.5
	200	9.3	9.0	8.7	8.7	8.8	7.6	7.3	8.5	7.1	6.9	5.7	5.5	6.3	5.2	4.7	4.3	4.0	4.1	4.5
	400	9.6	9.4	8.9	8.9	8.7	7.7	7.3	8.7	7.1	6.9	5.5	5.3	6.2	4.6	4.7	4.3	3.8	3.8	4.2
	800	9.7	9.4	9.0	9.0	8.8	7.8	7.4	8.8	7.0	6.9	5.5	5.3	6.2	4.5	4.6	4.2	3.7	3.7	4.1

Table 17. Snow depth and temperatures, °C, of December, 1953, and January and February, 1954.

Depth, cm	Test plot	December 1.	4.	8.	16.	20.	28.	Mean	January 7.	13.	21.	27.	Mean	February 3.	10.	15.	18.	Mean
Air,	2 m	—0.5	1.6	0.8	—1.9	—4.3	—1.7	—	—15.5	—6.6	—8.0	—10.0	—	—4.0	—20.0	—21.9	—24.9	—
Snow depth, cm	0	—	—	—	8.5	16.0	16.0	—	10.0	16.0	20.0	20.0	16.5	24.5	26.0	26.0	26.5	25.8
	200	—	—	—	8.0	16.0	16.0	—	15.5	22.0	29.0	29.0	23.9	31.5	32.0	32.0	32.0	32.0
	400	—	—	—	8.0	16.0	16.0	—	14.5	20.0	25.0	25.0	21.1	28.5	30.0	30.0	30.0	30.0
	800	—	—	—	8.5	16.0	16.0	—	12.5	17.5	20.0	20.0	17.5	20.0	18.5	18.5	18.0	19.0
Soil surface	0	—	—	—1.7	—1.1	—1.0	—0.3	—	—6.8	—1.8	—2.0	—2.1	—3.2	—1.5	—5.4	—6.0	—6.4	—4.8
	200	—	—	—1.2	—1.3	—1.1	—0.3	—	—2.5	—1.3	—1.4	—1.4	—1.7	—1.1	—3.5	—4.9	—5.5	—3.8
	400	—	—	—0.4	—1.3	—1.2	—0.3	—	—3.1	—1.6	—1.8	—1.9	—2.1	—1.3	—4.9	—5.1	—5.7	—4.3
	800	—	—	—1.2	—1.2	—1.2	—0.3	—	—5.4	—1.9	—2.0	—2.2	—2.9	—1.6	—5.9	—6.9	—7.6	—5.5
5	0	0.2	0.2	0.1	—0.4	—0.3	—0.1	—0.0	—1.3	—0.9	—0.9	—1.0	—1.0	—1.4	—1.8	—4.5	—5.1	—3.2
	200	0.0	0.1	0.0	—0.6	—0.5	—0.2	—0.0	—0.9	—0.8	—0.7	—0.7	—0.8	—0.9	—1.6	—3.2	—4.0	—2.7
	400	0.0	0.1	0.1	—0.4	—0.4	—0.1	—0.1	—1.0	—0.8	—0.7	—0.8	—0.8	—1.1	—2.0	—3.3	—4.2	—2.7
	800	0.0	0.0	0.1	—0.6	—0.7	—0.2	—0.2	—1.3	—1.1	—1.1	—1.1	—1.2	—1.6	—2.6	—4.6	—5.5	—3.6
10	0	0.2	0.2	0.2	—0.3	—0.3	—0.1	—0.0	—0.4	—0.5	—0.5	—0.6	—0.5	—0.8	—1.2	—2.8	—3.2	—2.0
	200	0.0	0.1	0.2	—0.5	—0.3	—0.1	—0.0	—0.6	—0.5	—0.5	—0.5	—0.5	—0.6	—1.0	—2.0	—2.7	—1.6
	400	0.0	0.0	0.1	—0.2	—0.2	—0.1	—0.1	—0.8	—0.6	—0.6	—0.6	—0.7	—0.8	—1.4	—2.1	—2.9	—1.8
	800	0.0	0.1	0.1	—0.6	—0.5	—0.1	—0.2	—1.1	—0.9	—0.9	—0.9	—1.0	—1.3	—2.3	—3.1	—4.0	—2.7
20	0	0.0	0.1	0.2	0.1	0.1	0.0	0.1	—0.1	—0.2	—0.2	—0.2	—0.2	—0.3	—0.6	—0.8	—1.2	—0.7
	200	0.0	0.0	0.2	—0.1	—0.1	—0.1	—0.0	—0.2	—0.2	—0.2	—0.2	—0.2	—0.2	—0.3	—0.6	—1.0	—0.5
	400	0.0	0.1	0.2	—0.1	—0.1	0.0	0.0	—0.2	—0.2	—0.2	0.2	—0.2	—0.3	—0.4	—0.7	—1.2	—0.7
	800	0.0	0.1	0.2	—0.2	—0.3	0.0	—0.0	—0.4	—0.4	—0.5	—0.5	—0.5	—0.7	—1.2	—1.9	—2.7	—1.6
50	0	2.2	2.1	2.1	1.5	1.4	1.3	1.8	1.1	1.0	1.0	0.9	1.0	0.8	0.7	0.6	0.6	0.7
	200	1.5	1.5	1.4	1.2	1.2	1.2	1.3	0.9	0.9	0.9	0.8	0.9	0.7	0.7	0.6	0.6	0.7
	400	1.9	1.8	1.7	1.2	1.2	1.2	1.5	1.1	1.0	0.9	0.8	1.0	0.7	0.7	0.6	0.5	0.6
	800	1.2	1.1	1.0	0.9	1.0	1.0	1.0	0.7	0.6	0.6	0.5	0.6	0.4	0.3	0.2	0.2	0.3
100	0	3.5	3.4	3.4	3.0	2.9	2.8	3.2	2.5	2.4	2.2	2.1	2.3	2.1	2.0	1.9	1.8	2.0
	200	3.3	3.2	3.2	2.7	2.7	2.6	3.0	2.3	2.3	2.2	2.1	2.2	2.0	1.9	1.8	1.8	1.9
	400	3.2	3.1	3.0	2.7	2.4	2.3	2.8	2.2	2.2	2.1	2.0	2.1	2.0	1.9	1.7	1.6	1.8
	800	3.1	3.0	2.9	2.4	2.4	2.5	2.7	2.1	2.1	2.0	1.9	2.0	1.9	1.8	1.6	1.5	1.7

Table 18. Snow depth and temperatures, °C, of March, April and May, 1954.

Depth, cm	Test plot	March 4.	March 20.	March 30.	March Mean	April 6.	April 17.	April 28.	April Mean	May 6.	May 14.	May 19.	May 22.	May 27.	May Mean
Air,	2 m	—3.4	0.2	0.0	—	—1.0	3.5	2.8	—	10.3	2.4	14.6	13.6	13.5	—
Snow depth, cm	0	30.0	26.0	25.0	27.3	26.0	20.0	—	—	—	—	—	—	—	—
	200	35.0	30.0	30.0	31.7	30.0	20.0	—	—	—	—	—	—	—	—
	400	30.0	27.5	26.0	27.8	22.5	15.0	—	—	—	—				
	800	30.0	28.5	26.5	28.3	21.0	10.0	—	—	—	—	—	—	—	—
Soil surface	0	—1.9	—0.7	—0.8	—1.1	0.0	0.8	—	—	—	—	—	—	—	—
	200	—1.3	—0.7	—0.8	—0.9	0.0	0.0	—	—	—	—	—	—	—	—
	400	—2.0	—0.7	—0.8	—1.2	0.0	0.4	—	—	—	—	—	—	—	—
	800	—2.0	—0.6	—0.5	—1.0	0.0	2.8	—	—	—	—	—	—	—	—
5	0	—1.2	—0.8	—0.4	—0.8	—0.2	—0.1	3.2	1.0	3.5	7.8	9.0	8.2	12.5	8.2
	200	—1.0	—0.8	—0.6	—0.8	—0.5	—0.1	2.9	0.8	3.3	7.5	8.2	8.0	11.5	7.7
	400	—1.3	—0.9	—0.5	—0.9	—0.4	—0.2	2.7	0.7	3.5	7.6	8.2	8.2	10.9	7.7
	800	—1.5	—0.8	—0.6	—1.0	—0.4	—0.2	2.0	0.5	4.2	7.9	8.7	8.8	12.8	8.5
10	0	—0.8	—0.6	—0.3	—0.6	—0.1	—0.2	0.1	—0.1	0.1	2.5	4.7	5.3	8.2	4.2
	200	—0.9	—0.6	—0.5	—0.7	—0.4	—0.3	—0.1	—0.3	1.6	3.7	5.7	6.0	7.1	4.8
	400	—1.1	—0.6	—0.5	—0.7	—0.4	—0.2	—0.1	—0.2	2.0	4.0	6.0	6.4	8.8	5.5
	800	—1.5	0.7	0.5	0.9	—0.4	0.2	0.1	0.2	2.9	4.7	7.7	7.8	10.3	6.7
20	0	—0.8	—0.5	—0.5	—0.6	—0.3	—0.2	—0.1	—0.2	—0.1	0.2	0.1	0.3	0.9	0.3
	200	—0.6	—0.5	—0.4	—0.5	—0.4	—0.4	—0.1	—0.3	—0.2	0.1	2.6	3.2	3.8	1.9
	400	—0.9	—0.5	—0.4	—0.6	—0.4	—0.2	—0.1	—0.2	—0.2	0.0	2.0	3.0	4.4	1.9
	800	—1.2	—0.5	—0.5	—0.7	—0.5	—0.3	0.0	—0.3	0.7	2.1	3.9	5.3	7.0	3.8
50	0	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.5	0.0	0.3	0.3	0.2	0.0	0.2
	200	0.5	0.4	0.3	0.4	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.0	0.2
	400	0.4	0.2	0.2	0.3	0.1	0.1	0.1	0.1	0.0	0.2	0.2	0.3	0.2	0.2
	800	0.1	0.1	0.1	0.1	—0.1	—0.2	—0.1	—0.1	0.0	0.0	0.1	0.3	0.1	0.1
100	0	1.7	1.6	1.5	1.6	1.4	1.3	1.3	1.3	0.7	0.7	0.7	0.7	0.8	0.7
	200	1.7	1.5	1.4	1.5	1.3	1.1	0.6	1.0	0.7	0.9	0.9	0.9	1.0	0.9
	400	1.5	1.4	1.4	1.4	1.3	1.1	0.6	1.0	0.7	0.8	0.9	0.8	1.0	0.8
	800	1.4	1.2	1.2	1.3	1.1	0.9	0.6	0.9	0.7	0.7	0.8	0.8	0.9	0.8

Table 19. Mean temperatures of June and July, 1954, °C.

Depth, cm	Test plot	June								July					
		7.	11.	15.	18.	22.	26.	30.	Mean	6.	8.	15.	21.	28.	Mean
Air,	2 m	7.1	17.5	15.7	16.5	18.3	13.6	14.8	—	20.4	19.9	20.1	12.6	16.1	—
5	0	7.8	14.3	13.6	14.2	14.7	14.8	14.3	13.4	16.5	19.7	19.5	15.2	15.3	17.3
	200	7.0	13.8	14.4	14.4	14.5	15.0	14.2	13.4	16.1	18.8	18.7	15.1	14.6	16.7
	400	8.0	13.9	14.9	15.0	15.0	15.1	14.3	13.8	15.9	18.9	18.8	15.2	14.6	16.7
	800	8.0	13.7	12.7	14.8	15.0	15.2	14.3	13.4	15.9	18.8	18.8	15.4	14.7	16.7
10	0	5.1	9.7	10.1	11.5	14.0	14.1	13.0	11.1	15.5	17.0	17.8	15.0	14.6	16.0
	200	5.9	11.3	12.3	12.8	14.2	14.5	14.0	12.2	15.6	17.3	18.2	15.1	14.3	16.1
	400	6.2	11.2	12.6	13.2	14.4	14.7	13.7	12.3	15.7	17.7	18.3	15.1	14.5	16.3
	800	6.5	11.6	13.3	14.0	14.8	15.2	14.0	12.8	15.8	17.9	18.4	15.3	14.6	16.4
20	0	1.8	4.4	5.5	5.5	9.0	10.2	10.9	6.8	12.9	14.0	16.0	14.2	14.1	14.3
	200	3.0	7.0	8.6	8.7	11.8	11.8	12.1	9.0	14.3	15.0	17.0	14.4	14.2	15.0
	400	3.0	7.2	9.9	9.2	12.0	12.2	12.4	9.4	14.5	15.4	17.4	14.9	14.4	15.4
	800	4.2	8.5	10.8	10.7	13.8	13.4	13.0	10.6	15.7	16.3	19.3	15.7	14.6	16.4
50	0	0.1	0.1	0.1	0.1	3.3	6.0	7.4	2.5	9.0	9.8	11.6	11.2	11.9	10.7
	200	0.9	2.9	4.2	5.0	6.6	8.7	9.2	5.4	10.4	11.0	12.7	12.5	12.2	11.7
	400	0.7	2.8	4.7	5.0	6.7	8.7	9.3	5.4	10.4	11.0	12.6	12.9	12.2	11.7
	800	1.0	3.2	5.4	6.5	8.0	9.5	9.7	6.2	11.0	11.9	13.7	12.9	12.9	12.5
100	0	0.7	0.8	0.8	0.8	3.2	3.4	4.1	2.0	5.7	6.0	7.0	7.5	8.2	6.9
	200	1.0	1.2	1.6	2.0	4.4	5.4	5.9	3.1	7.3	7.3	8.5	8.6	9.0	8.2
	400	1.0	1.4	1.7	2.1	4.3	5.5	6.7	3.2	7.5	7.7	8.5	8.7	9.4	8.4
	800	1.0	1.4	1.7	2.3	4.4	5.6	6.3	3.2	7.5	7.7	8.7	9.0	9.7	8.6

Table 20. Mean temperatures of August and September, 1954, °C

Depth, cm	Test plot	August						September		
		6.	12.	18.	23.	26.	Mean	2.	27.	Mean
Air,	2 m	12.2	15.4	13.4	14.2	12.3	—	8.4	8.7	—
5	0	13.7	15.4	15.6	14.6	13.5	14.6	9.9	9.6	9.8
	200	13.7	15.3	15.3	14.2	13.2	14.4	9.8	9.1	9.5
	400	14.0	14.9	14.9	14.0	13.2	14.2	10.3	9.1	9.7
	800	13.9	14.9	15.0	14.5	13.4	14.4	10.0	9.0	9.5
10	0	13.6	14.1	14.2	13.4	13.0	13.7	10.7	8.9	9.8
	200	14.1	14.2	14.1	13.5	13.0	13.8	10.3	8.7	9.6
	400	14.2	14.4	14.5	13.7	13.1	14.0	10.5	8.7	9.7
	800	14.0	14.1	14.2	14.0	13.6	14.0	10.3	8.7	9.6
20	0	14.1	14.1	13.2	12.4	11.3	13.0	10.8	8.6	9.7
	200	14.3	14.4	13.4	12.6	11.5	13.3	10.7	8.6	9.7
	400	14.7	14.5	13.4	12.8	11.4	13.4	10.8	8.6	9.7
	800	14.7	14.8	13.7	13.3	11.5	13.6	10.8	8.6	9.8
50	0	12.0	12.8	12.2	11.5	10.8	11.9	10.6	8.8	9.7
	200	12.5	13.0	12.5	11.5	11.2	12.2	10.7	8.5	9.6
	400	12.8	13.3	12.6	11.3	11.0	12.2	10.7	8.6	9.7
	800	13.0	13.1	12.6	11.7	11.3	12.4	10.9	8.3	9.6
100	0	9.3	10.5	9.5	8.9	8.5	9.4	8.6	8.2	8.4
	200	9.5	10.5	10.2	9.5	9.2	9.8	8.9	8.3	8.7
	400	10.0	10.7	10.3	9.6	9.0	10.0	9.0	8.2	8.6
	800	10.0	10.8	10.3	9.8	9.2	10.0	9.2	8.3	8.8

A comparison between the mean temperatures of the winter months is difficult to institute, since the snow-cover was not similar on all test plots. At a snow density of 0.12 g/cm^3 its thermal conductivity has been found to range from 0.00010 to 0.00028 cal./cm · sek · °C (ETIENNE 1940, p. 155, KERÄNEN 1920, p. 97, NIEDERDORFER 1933). The corresponding values for snow of density 0.16 g/cm^3 are 0.00017—0.00047. The values are of the same order of magnitude as the thermal conductivity of dry peat (SMITH 1938, p. 17). The density of the snow having been lower in the early winter than in its latter part (fig. 10, p. 30), equal differences in snow depth give rise to greater differences in the temperature below the snow-cover in the early part of the winter than in its latter part. It may be mentioned as an illustration of the poor thermal conductivity of newly fallen, loose snow that on 4. XII. 1952 the vertical temperature difference over 13 cm of snow was as much as 11 °C. (Cf. KERÄNEN 1920, pp. 163, 177; SIMOLA 1926, p. 27).

Fig. 13 gives the best general picture of the monthly temperature differences between the test plots. However, it should be borne in mind that the test soil was bare in the summer of 1954, whereas it grew oats during the preceding summer.

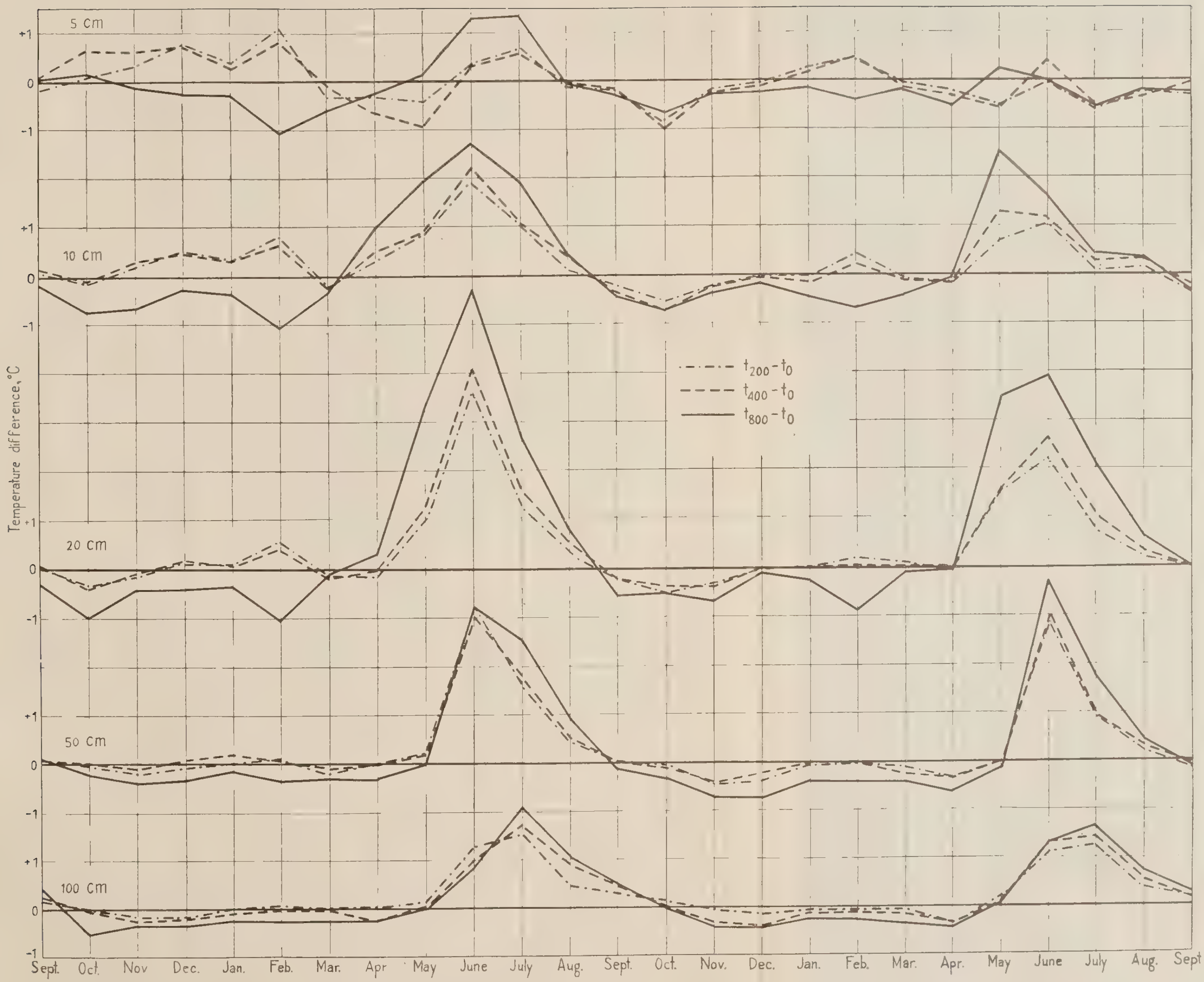

Fig. 13. Differences between the monthly mean temperatures in the soil from September 1952, to September, 1954.

Table 21. Temperature differences.

Depth, cm	$t_{200}-t_0$, 400, 800	1952				1953						1954				3-year mean		2-year mean						2-year mean
		VI	VII	IX	X	V	VI	VII	VIII	IX	X	V	VI	VII	VIII	VI	VII	V	VI	VII	VIII	IX	X	V—VIII
5	$t_{200}-t_0$	—	—	−0.3	0.2	−0.4	0.3	0.6	−0.2	−0.2	−0.9	−0.5	0.0	−0.6	−0.2	—	—	−0.5	0.2	0.0	−0.2	−0.3	−0.4	−0.1
	$t_{400}-t_0$	0.7	1.6	0.0	0.7	−1.0	0.3	0.5	−0.1	−0.1	−1.0	−0.5	0.4	−0.6	−0.4	0.5	0.5	−0.8	0.4	−0.1	−0.3	−0.1	−0.2	−0.2
	$t_{800}-t_0$	1.6	2.2	0.0	0.2	0.1	1.3	1.3	−0.1	−0.2	−0.8	0.3	0.0	−0.6	−0.2	1.0	1.0	0.2	0.7	0.4	−0.2	−0.1	−0.3	0.3
10	$t_{200}-t_0$	—	—	0.0	−0.2	0.4	1.9	1.1	0.2	0.2	−0.3	0.6	1.1	0.1	0.1		—	0.5	1.5	0.6	0.2	−0.1	−0.3	0.7
	$t_{400}-t_0$	0.8	1.3	0.1	0.1	0.4	2.2	1.2	0.4	−0.3	0.7	1.3	1.2	0.3	0.3	1.4	0.9	0.9	1.7	0.8	0.4	−0.1	−0.4	0.9
	$t_{800}-t_0$	2.1	1.8	−0.1	−0.7	1.9	2.8	2.0	0.5	−0.4	−0.7	2.5	1.7	0.4	0.3	2.2	1.4	2.2	1.8	1.2	0.4	−0.3	−0.7	1.4
20	$t_{200}-t_0$	—	—	0.0	−0.3	0.9	3.6	1.3	0.4	−0.2	−0.5	1.6	2.2	0.7	0.3	—	—	1.3	2.9	1.0	0.4	−0.1	−0.4	1.4
	$t_{400}-t_0$	1.7	1.7	0.0	−0.4	1.1	4.0	1.7	0.6	−0.3	−0.4	1.6	2.6	1.1	0.4	2.8	1.5	1.4	3.3	1.4	0.5	−0.2	−0.4	1.6
	$t_{800}-t_0$	2.1	2.5	−0.3	−1.0	3.3	5.8	2.8	0.9	−0.6	−0.5	3.5	3.8	2.1	0.6	3.9	2.5	3.4	4.8	2.5	0.8	−0.5	−0.3	2.9
50	$t_{200}-t_0$			0.1	0.0	0.2	3.1	1.7	0.5	0.0	−0.1	0.0	2.9	1.0	0.3		—	0.1	3.0	1.4	0.4	0.1	−0.1	1.2
	$t_{400}-t_0$	—	—	0.1	0.0	0.1	3.0	1.8	0.6	0.0	−0.2	0.0	2.9	1.0	0.3	—	—	0.1	3.0	1.4	0.5	0.1	−0.1	1.2
	$t_{800}-t_0$	—	—	0.2	−0.2	−0.1	3.2	2.6	1.0	−0.1	−0.4	−0.1	3.7	1.8	0.5	—	—	−0.1	3.5	2.2	0.8	0.1	−0.3	1.6
100	$t_{200}-t_0$	—	—	0.2	0.0	0.1	1.2	1.5	0.5	0.2	0.1	0.2	1.1	1.3	0.4	—	—	0.2	1.2	1.4	0.5	0.2	0.1	0.8
	$t_{400}-t_0$	—	—	0.2	0.0	−0.1	0.9	1.7	1.0	0.4	0.0	0.1	1.2	1.5	0.6	—		0.0	1.1	1.6	0.8	0.3	0.0	0.9
	$t_{800}-t_0$	—	—	0.4	0.0	0.2	0.8	2.1	1.1	0.5	0.0	0.1	1.2	1.7	0.6			−0.1	1.0	1.9	0.9	0.5	0.0	1.1

The temperature differences at 5 cm depth do not always behave in a regular way. A distinct regularity is only observable in the year 1953, the mean temperatures on the plots with mineral soil admixture exceeding those on the control plot in June and July and the cooling of the soil in the autumn being slower on plot 0 than on the others. The differences in the mean temperatures of the winter months cannot be entirely explained even on the basis of the different snow-cover.

At 10 cm depth the course of the mean temperature differences is similar to that at 5 cm depth. Furthermore, at this depth also the mean temperatures of the summer 1954 are higher on the test plots improved with mineral soil than on plot 0. The higher rate of cooling of the soil on the mineral soil plots is similarly visible in October, 1953.

At 20 cm depth the greatest differences in the mean temperatures of the summer months occur in comparison with other depths, except for the depth of 50 cm in June, 1954. In Feilitzen's (1902, p. 146—147) investigations, the greatest temperature differences among his depths of measurement, 20, 40 and 60 cm, occurred at this same depth, namely, 20 cm. It is further seen from fig. 13 that the cooling of the soil in the autumn takes place with a high degree of regularity at 20 cm depth.

In view of the fact that the deviations between the temperature observations of the replicates at this depth were quite small in all the test plots and that in at least three of the plot the thermocouples were situated at approximately the same depth (table 5), the temperature differences obtained for this depth can be considered adequately fairly representative of the actual conditions obtaining during the snow-free months.

Temperature differences are also observable at the depths of 50 and 100 cm. At 100 cm depth, however, the differences of the mean temperatures diverge in behaviour from those at the other depths, in that the greatest differences from the mean temperatures in plot 0 occur in July, not in June as at the other depths. It can also be noticed that the different quality of the snow-cover is unable to alter the fact that the temperature at 50 and 100 cm depth is lower in the wintertime in the test plots with mineral soil admixture than in plot 0.

A general review of the temperatures at all depths in the wintertime shows that the differences from plot 0 scarcely exceed 1°C at any depth.

It appears to be a characteristic feature of the monthly mean temperatures that their differences are distinct in the spring and in the middle of the summer (fig. 13), whereas they tend to diasppear during the autumn. It may be mentioned that this was also observable in the investigations of Wollny (1891) and that Fleischer's (1891, p. 835) measurements showed temperature differences of 5.0 and 6.6 C at 11 cm depth on 2. IV. 1879. This phenomenon also furnishes an explanation for the small tem-

perature differences between the test plots found by Vesikivi (1933, p. 3—5) in his measurements in the autumn of 1928. As can be seen from his measurements, on the other hand, the daily variation of the temperature on the different test plots presents a distinctly different picture, thus indicating a difference in thermal conductivity between the soils compared.

From a practical viewpoint the thermal conditions during the growth period are of primary significance. In table 21 the differences in mean temperature of the months of the growing season and further of October and of the period May to August have been compiled. With regard to June and July the mean values of three years and from three depths are available, with the exception of test plot 200. The greatest mean temperature differences have occurred in June at 20 cm depth. Among the three years the year 1953 has produced the greatest temperature differences.

It is found from the means of two years' observations that at 5 cm depth the mean temperature of plot 0 remains lower than that of any other plot in June and further lower than the mean temperature of test plot 800 in May and July also. At 10 and 20 cm depths the mean temperature of plot 0 is lower than that of any other plot in all other months except September and October. At 50 cm depth the mean temperature of plot 0 exceeds the others only in October, and at 100 cm depth it is generally always lower than the corresponding temperature in any other plot. The last column of the table shows that there are no noteworthy differences between the mean temperatures at 5 cm depth during the time May to August. At the other depths the differences were quite distinct, reaching their maximum at 20 cm depth.

It is seen from tables 11—21 and from fig. 13 that the temperature differences between test plots 400 and 200 are surprisingly small. Since the temperature differences at 20 cm depth are comparatively insignificant, it is quite plausible that no greater temperature differences occur even at the greater depths, since the mineral soil was admixed with a layer of about 20 cm depth. The small differences between test plots 400 and 200 will be the subject of renewed comment later.

It was already evident from the differences between the monthly mean temperatures (fig. 13) that the temperature differences between plot 0 and the plots improved with mineral soil are greatest in the spring and early summer. The variation of the temperature differences at 10 and 20 cm depth during the snow-free months is seen in greater detail from fig. 14. It is seen that the maximum of the temperature differences between plot 0 and the other plots at 10 cm depth occurs in both years in the middle of June. However, the observations of 1954 show that this is not rigidly correlated with the time of year. On the contrary, weather conditions have a considerable influence, so that in 1954 nearly as great temperature

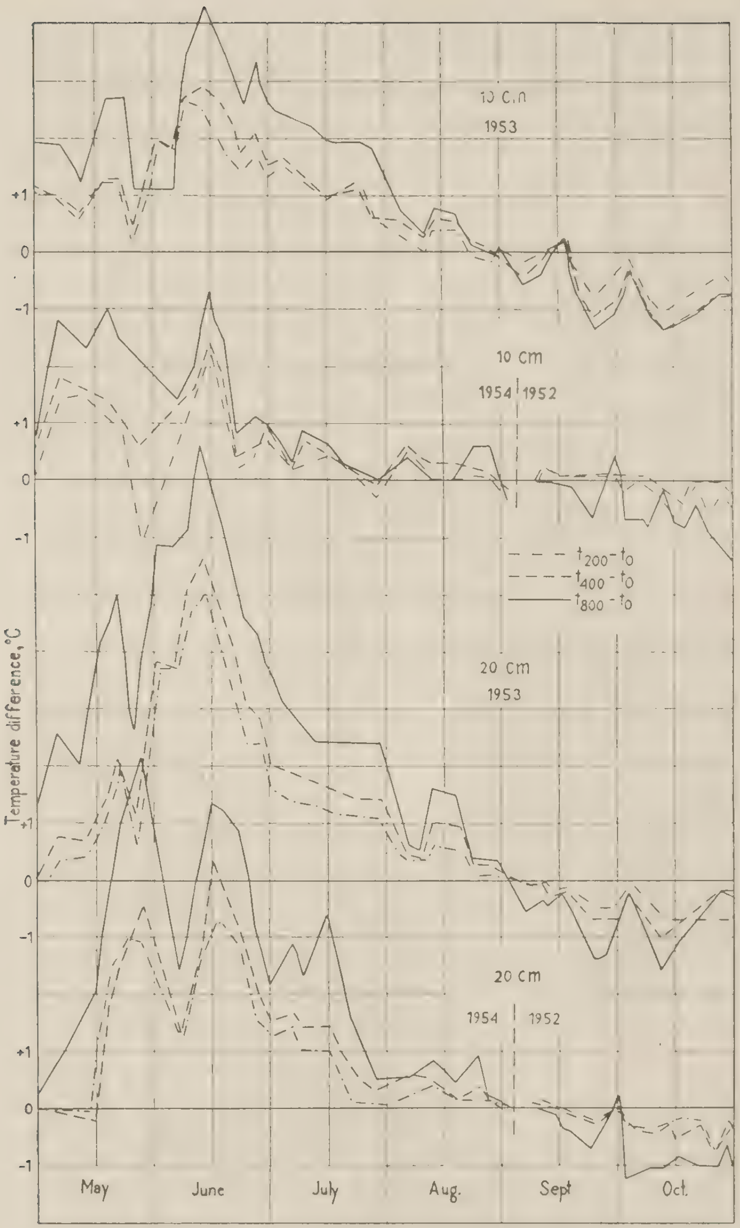

Fig. 14. Differences between the daily mean temperatures in the soil during May to October at 10 and 20 cm depths.

differences occur in May as in June. In the year 1954, during which the test area was bare of vegetation, the temperature differences of July and August were low in comparison with those of the preceding year.

The maxima of the temperature differences at 20 cm depth occurred in 1953 in the middle of June, but in 1954 partly as early as May. The maximum of the temperature difference between plots 800 and 0 is in May and those between plots 400 and 200 and plot 0 in June. The different time of occurrence of the maxima in the said years is attributable to the weather conditions of the different months. In 1953, June was very warm, 5.4°C above normal (table 3), whereas in 1954 the mean temperature of May exceeded the normal by 3.9°C. It seems to be a characteristic feature of the temperature differences between test plot 800 and the plots 400 and 200 at both these depths that as a rule the temperature differences are greater in the early spring than later in the summer.

The variations of the temperature at 50 and 100 cm depth are remarkably smooth. It is seen from tables 14, 15 and 19 that the maximum difference is reached at 50 cm depth soon after the middle of June and at 100 cm depth at the end of June and beginning of July.

In what follows, a theoretical study is made of the temperatures on test plots 800 and 0 and of the differences between these plots from May 15 to October.

The method is based upon the theory of the motion of heat in the soil presented by FOURIER (1884) and POISSON (1835) (see KERÄNEN 1929 and SCHUBERT 1930). Numerous investigators have employed this theory in their studies of the temperature of the soil or of the snow-cover (HOMÉN 1896, KERÄNEN 1920, HADAS 1952 etc.).

The theory is based on the fact that the periodic changes in the soil temperatures conform approximately to sine or cosine curves. It is thus possible to represent the series of temperature measurements from some depth in the soil mathematically with the aid of a sine curve. In its more elaborate form this is referred to as harmonic analysis. The curves may have different shapes, further their maxima and minima may occur on different abscissae in the coordinate system when curves relating to the temperatures at different depths are examined.

The theoretical study is made as follows.

The monthly mean temperatures of the said months were first plotted and approximated to a sine curve, the temperatures of the soil surface having been obtained by extrapolation from the measurements of 1953 and 1954. For the determination of the equation of the sine curve, (see HANN-SÜRING 1939, p. 82) the soil surface temperatures of the other months were plotted symmetrically to the mean temperatures of the summer months, neglecting the influence of snow-cover and frozen ground

upon the thermal conditions in the soil. The equation representing the soil surface temperature is

$$t_o = t_m + A \sin (\omega t + \alpha)$$

where t_o = the soil surface temperature, t_m = the mean temperature, A = amplitude, $\omega = \frac{2\pi}{T}$ (T = period of the sine wave), t = time and α = phase. The equation arrived at in this way for the sine curve representing the soil surface temperature is

$$t_o = 1.9^\circ + 16.5^\circ \sin (259.4^\circ + 30\,t)$$

Assuming that thermal conductivity (λ) and the specific heat according to volume (C) are constant, the temperature representing a certain depth can be represented by the equation

$$t_x = t_m + \mathrm{A}e^{-x/D} \sin (\omega t - x/D + \alpha)$$

where e = the base of the natural logarithms, and $D = \sqrt{\frac{2\lambda}{C\omega}} = \sqrt{\frac{2K}{\omega}}$ (K = thermal diffusivity). On the basis of this equation, corresponding equations were calculated for each depth of the test plot 0 at which temperature measurements had been carried out (table 22).

Table 22. Amplitude (A_h) and time lag of the extremes (r) of theoretically calculated sine curves for the various depths, test plot 0.

Depth	A_h °C	r°
Soil surface	16.5	259.4
5 cm	15.7	256.7
10 cm	15.2	254.1
20 cm	14.0	249.4
50 cm	10.8	234.5
100 cm	7.0	209.5

After this the temperatures for the test plot 800 at 5, 10 and 20 cm depths were calculated in the following approximate way: It has been assumed that the temperature of the soil surface follows a curve similar to that plot 0. The observations seem to indicate that this is so. Furthermore it has been assumed that the thermal flow is similar in the soil surface of both test plots and is independent of depth in the 0—20 cm layer. On the basis of these assumptions it is possible to write the equation

$$t_{800}\ x\ \mathrm{cm} - t_{800}\ o\ \mathrm{cm} = \frac{\lambda_0}{\lambda_{800}} (t_0\ x\ \mathrm{cm} - t_0\ o\ \mathrm{cm})$$

by means of which the calculation can be performed.

The temperature for the depths 50 and 100 cm of the test plot 800 have been calculated on the basis of the temperature at 20 cm depth by the same method as was used in plot 0.

For the thermal conductivity the values appearing in table 29 were used. In the calculation relating to the depths of 5 and 10 cm of plot 0 mean value of λ for the 0—10 cm layer was used; for the other depths, the corresponding value of the 0—20 cm layer. In the case of the test plot 800 the mean of the values of λ obtained for the 0—10 cm layer was used in the calculations relating to the depths of 5 and 10 cm, and correspondingly, for the 20 cm depth that of the 0—20 cm layer. For the greater depths the same value of λ was used as in the case of plot 0.

The temperatures on both test plots have been calculated from May 15 to October and the differences between the test plots at the depths of 5, 10 and 20 cm tabulated in table 23. On comparison of these

Table 23. Theoretically calculated tempetature differences between test plots 800 and 0 (t_{800}—t_0) 15 th of May to October, °C.

Depth	V	VI	VII	VIII	IX	X
5 cm	0.5	0.4	0.3	0.1	—0.1	—0.3
10 »	1.0	0.8	0.7	0.2	—0.2	—0.6
20 »	1.9	1.6	1.3	0.5	—0.5	—1.2

theoretical values with the temperature differences actually observed between test plots 800 and 0 (e. g. table 21 and figs. 13 and 14) it can be seen that agreement exists between the theoretical calculations and the experimental results in the following respects:

1. Temperature differences exist between the test plots in the spring and early summer, the addition of mineral soil having increased the soil temperature. In the autumn conditions are reversed.
2. The greatest temperature differences between the test plots 800 and 0 occur at the depths of 5 to 20 cm during the period May to June.
3. The temperature differences between the test plots increase from the soil surface to the depth of 20 cm and begin to decrease from here towards greater depth.
4. The temperature differences between the test plots as calculated in accordance with the theoretical calculations are of nearly the same magnitude as those actually observed at all depths in September and October.

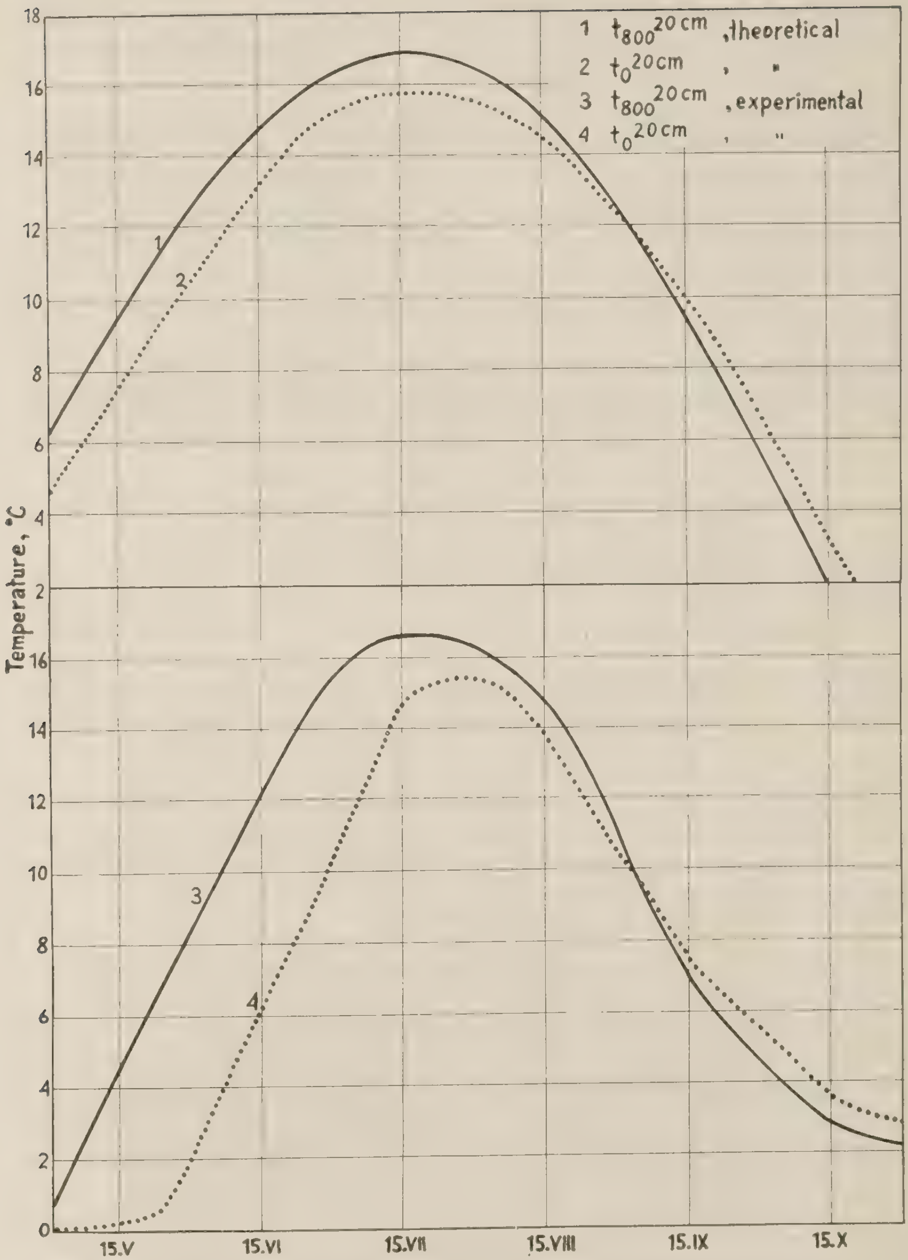

Fig. 15. Theoretical representation of the daily mean temperature at 20 cm depth on test plots 0 and 800, and experimental curves.

On the other hand, the tempertaure differences to be expected in accordance with the theoretical calculations differ considerably with the temperature differences actually observed in the spring and early summer, the theoretical values being smaller. Fig. 15 has been drawn in order to explain this phenomenon. It shows graphically the variation of the temperature at 20 cm depth in both test plots both according to the theoretical calculations and on the basis of the actual observations. The values used for the plotting of this latter curve are means from two years. If further study is made of the curves relating to the period May to October, it is seen that actually the increase of temperature has started later in the spring, but at a higher rate, than according to the theory. It is further noticed that the great temperature differences between the test plots in the spring are due to the fact that the temperature rise has started about three weeks later on the test plot 0 than on plot 800. Once the temperature rise has started on plot 0, it has proceeded even there at approximately the same rate as on plot 800. The reason for this apparent discrepancy between theory and actuality will become evident on page 79.

As can be seen from tables 11—20, measurements were made from the autumn 1952 onwards at intervals of a few days, although it was not possible to keep the intervals regular. During the winter months observations were made on an average four times a month, whereas the number of days of observation in the summer months generally varied between five and seven. To what degree this enables us to establish the differences in soil temperature between the test plots, is shown in table 24. This table contains the differences in mean temperature of the various depths against the mean temperatures of the test plot 0 as calculated separately for all days of observation (on three days no observations were made), next on the basis

Table 24. Differences between mean temperatures as calculated in various ways, from 18. VI—15. VII. 1952.

	Depth, cm	$t_{400}—t_0$ and $t_{800}—t_0$ as calculated on the basis of every day (1.), every second (2.) . . . every 7th (7.) day						
		1.	2.	3.	4.	5.	6.	7.
$t_{400}—t_0$	5	1.2	1.3	1.3	1.3	1.1	1.2	1.3
	10	1.1	1.2	1.0	0.9	1.1	0.7	1.1
	20	1.7	1.7	1.7	1.7	1.4	1.5	1.7
	30	1.7	1.7	1.8	1.8	1.5	1.6	1.6
$t_{800}—t_0$	5	2.0	2.0	2.1	1.8	2.0	1.8	2.2
	10	1.9	1.9	1.9	1.7	1.9	1.6	2.0
	20	2.6	2.6	2.6	2.5	2.3	2.3	2.6
	30	2.3	2.3	2.3	2.3	2.0	2.1	2.1
Average		1.8	1.8	1.8	1.8	1.7	1.6	1.8

of every second day, etc., up to the values calculated from observations made every seventh day.

It is seen from the table that no great differences appear in the values of the mean temperature difference, whichever of these methods of calculation is chosen, even that taking into account only every seventh day. The inaccuracy caused by the fact that observations were only made at intervals of a few days is thus without practical significance. As the primary objective was to study the temperature differences between the test plots, it was not considered necessary to perform measurements every day, which would indeed have entailed insurmountable practical difficulties. Considering, moreover, that particularly in June, to which month the series presented in table 24 refers, the soil temperature displays quite considerable variations, as will be found later, it is likely that the deviation of the monthly mean temperature differences calculated for the different months of the correct values are even smaller than those in table 24. The corresponding calculation concerning to the mean temperatures indicated that these were correct within 0.4—0.5°C when they were calculated from observations made every seventh day.

It has been pointed out before that the differences in mean temperature at 5 cm depth were of an entirely different order in 1953 and in 1954. One of the reasons is probably the absence of plant cover in 1954. In table 25 mean temperature values from the 5 cm depth of very nearly similar days of both years have been compiled. Determinations of soil moisture are not available in all cases, but in the choice of these days the periods of rain have been taken into account so that in all probability the moisture content of the soil was nearly the same on those days which have been compared with each other in the table.

The comparison shows that in the case of a plant-covered test plot, i. e., under conditions corresponding to those encountered in practice, the

Table 25. The influence of the plant cover upon the mean temperatures in the soil at 5 cm depth in the different test plots.

Date	Mean air temp. at 2 m height, °C	Mean soil temp. at 5 cm depth, °C				Hours of sunshine	Plant cover
		0	200	400	800		
15. VII. 1953 ..	16.2	16.2	16.8	16.3	17.7	8 1/2	oats
8. VII. 1954 ..	19.9	19.7	18.8	18.9	18.8	9	none
1. VII. 1953 ..	16.5	15.8	16.8	17.4	18.3	10 1/2	oats
15. VII. 1954 ..	20.1	19.5	18.8	18.8	18.9	6 1/2	none
28. VII. 1953 ..	17.1	17.0	16.9	16.9	17.4	1 1/2	oats
28. VII. 1954 ..	16.1	15.4	14.6	14.7	14.7	1	none
18. VIII. 1953 ..	16.5	16.8	16.7	16.7	16.8	4	oats
18. VIII. 1954 ..	13.4	15.7	15.4	14.9	15.0	5	none

mean temperature has remained lower in plot 0 than in the other plots. When the plant cover is absent, conditions are reversed. The absence of plant cover in May also explains the fact that even in 1953 not all the test plots improved with mineral soil displayed higher mean temperatures in May than plot 0. The reason for this effect of the plant cover will be gone into later.

No far-reaching inferences can be drawn with regard to the correlation between the differences in the mean soil temperatures and the weather conditions. According to table 3 the mean air temperatures of the different months have shown no remarkable deviation from normal except in June, 1953, and May, 1954. In these months the mean temperature differences at 20 cm depth were higher than at the corresponding time of the other years. The weather conditions in the years under investigation must otherwise be considered sufficiently representative for the results of the investigation to be said to give a relatively normal picture of the differences in mean temperature in the soil.

The possibility exists, however, that owing to the annual variation of the weather conditions the mean temperature differences presented may not completely reflect the true situation regarding the mean thermal conditions over long periods of time. A more reliable picture would be obtained if it were possible in these cases to express the effect achieved with the aid of mineral soil as a percentage of the maximum effect attainable. As a maximum effect, one might consider the difference in thermal conditions between pure mineral soil and pure peat soil. In connection with this investigation there was no opportunity to study the thermal conditions in pure mineral soil. However, in fig. 16 the theoretically derived mean

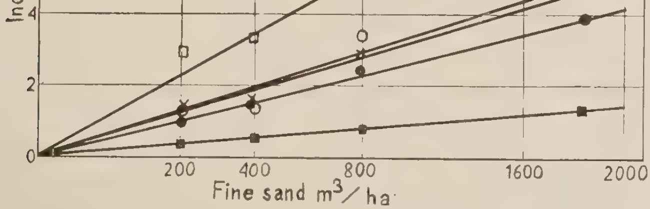

Fig. 16. Differences in mean temperature from test plot 0 in dependence on amount of mineral soil added; abscissae plotted in accordance with geometrical succession.

temperatures in pure mineral soil at 20 cm depth have been shown for some months and for the period May to August. They have been determined on the basis of the observation that the increase in mean temperature yields a fairly straight line when plotted against the quantity of mineral soil expressed in accordance with a geometric succession with the basis 200 and the ratio 3/2. The maximum effect of mineral soil will obtain when it is of such an amount that the 0—20 cm layer is pure mineral soil, i. e., 2 000 m³ ha. The temperature measurements made on mineral soil and peat in 1955 lend support to this hypothesis. When the increases in mean temperature caused by the different amounts of added mineral soil in this investigation are expressed in terms of the maximum effect of mineral soil, the following figures are obtained: The addition of 800 m³/ha has increased the mean temperatures by 54 %, that of 400 m³ ha by 36 and the addition of 200 m³/ha by 24 % of the maximum effect. These percentages constitute a fairly useful criterion of the advantage to be derived from the addition of different quantities of mineral soil.

d. *The annual variation of the temperature*

The annual variation of the soil temperature in the different test plots is seen from fig. 17. From the isotherms similar observations to those shown by the mean soil temperatures can be made with regard to the thermal conditions on the test plots.

The abrupt changes of the +1°C isotherm in April and in the first half of May, 1953, are probably due to the changes in ground-water level, as this extended at times up to 24 cm below the soil surface (table 4). On the other hand it is more difficult to find a reason for the abrupt descent of the same isotherms in the test plots 400 and 800 in the latter half of May of the same year, the ground-water level already being below the lowest measuring depth at this time. It is seen from table 14 that the descent of the isotherms causes a decrease in the temperature at 100 cm depth.

The ground-water does not seem to have any noteworthy influence upon the temperature differences in the soil. It was seen from table 4 that in the summer of 1954 the ground-water rose several times above the 100 cm depth. This occurred, for instance, during the time between 22. VI and 8. VII and again in the middle of August. However, the isotherms reveal that the rise of the ground-water level has not abolished the temperature differences between the test plots at 100 cm depth.

The disappearance of the 0°C isotherms about the middle of May does not signify that the frozen ground has thawed completely at this time. In 1953 the soil thawed in plot 0 on 10. VI and in the other plots on 1. VI, in 1954 on 5. VI in plots 800 and 400, on 7. VI in plot 200 and on 14. VI in plot 0.

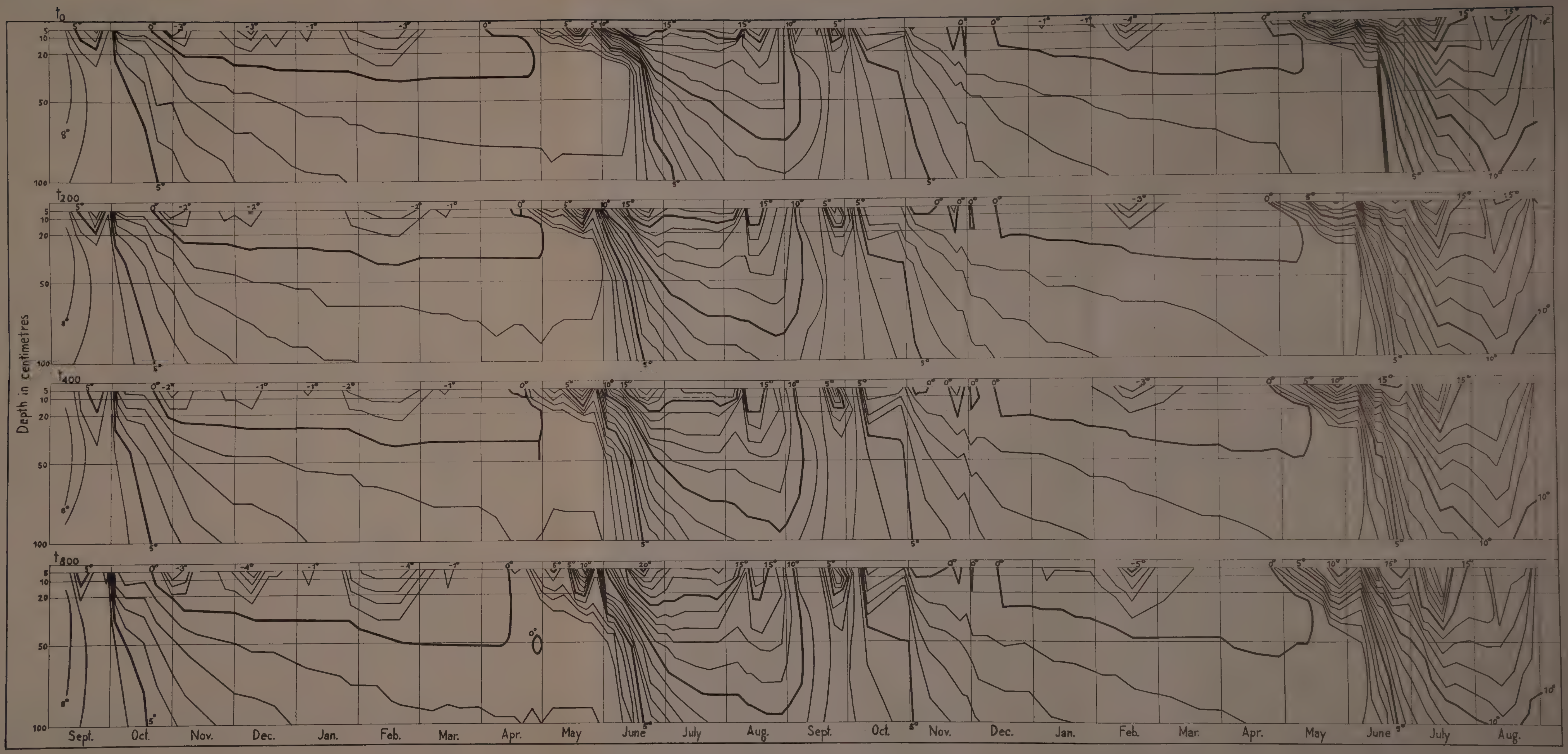

Fig. 17. Variation of the temperature in the soil at the depths 5 cm to 100 cm on the different test plots during the time 9. IX. 1952—2. IX. 1954.

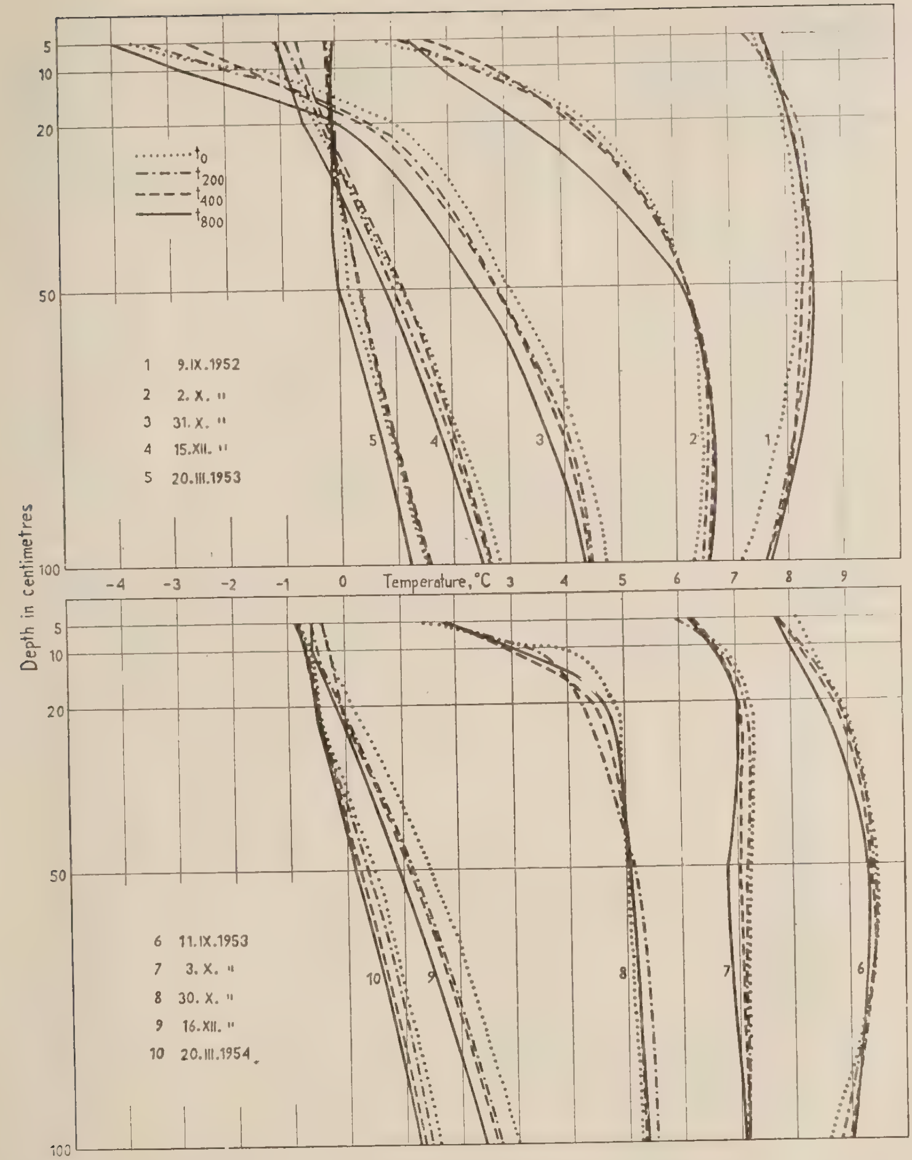

Fig. 18. Vertical temperature distribution on certain days.

The vertical distribution of temperature in the soil at the different times of the year is shown in figs. 18 and 19. Of these, fig. 18 represents the temperature distribution in the autumn and fig. 19 in the spring and summer.

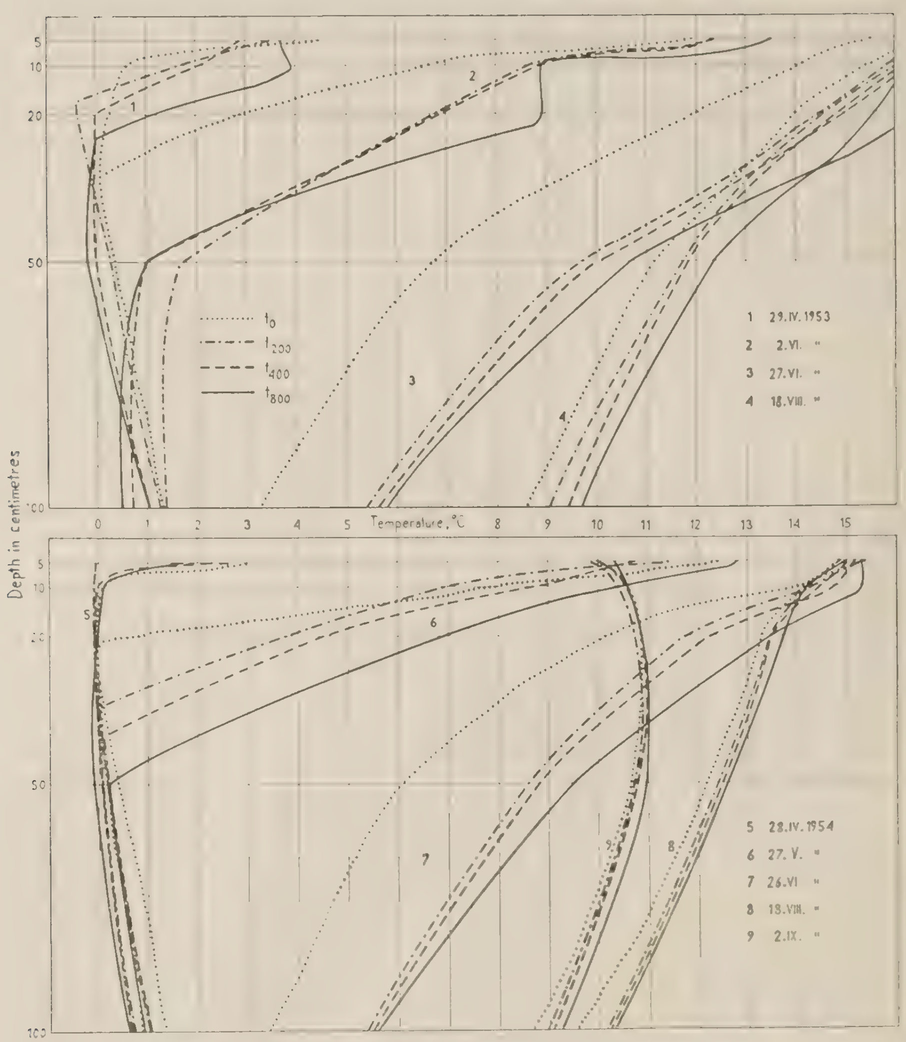

Fig. 19. Vertical temperature distribution on certain days.

e. *The daily variation of the temperature*

There are several factors which make the daily variation of the temperature in the soil diverge considerably on different days. Among such causes are the varying thermal conductivity of the soil in accordance with its moisture content, the variations of air temperature and cloudiness, and the changes in plant cover which take place during the growing season.

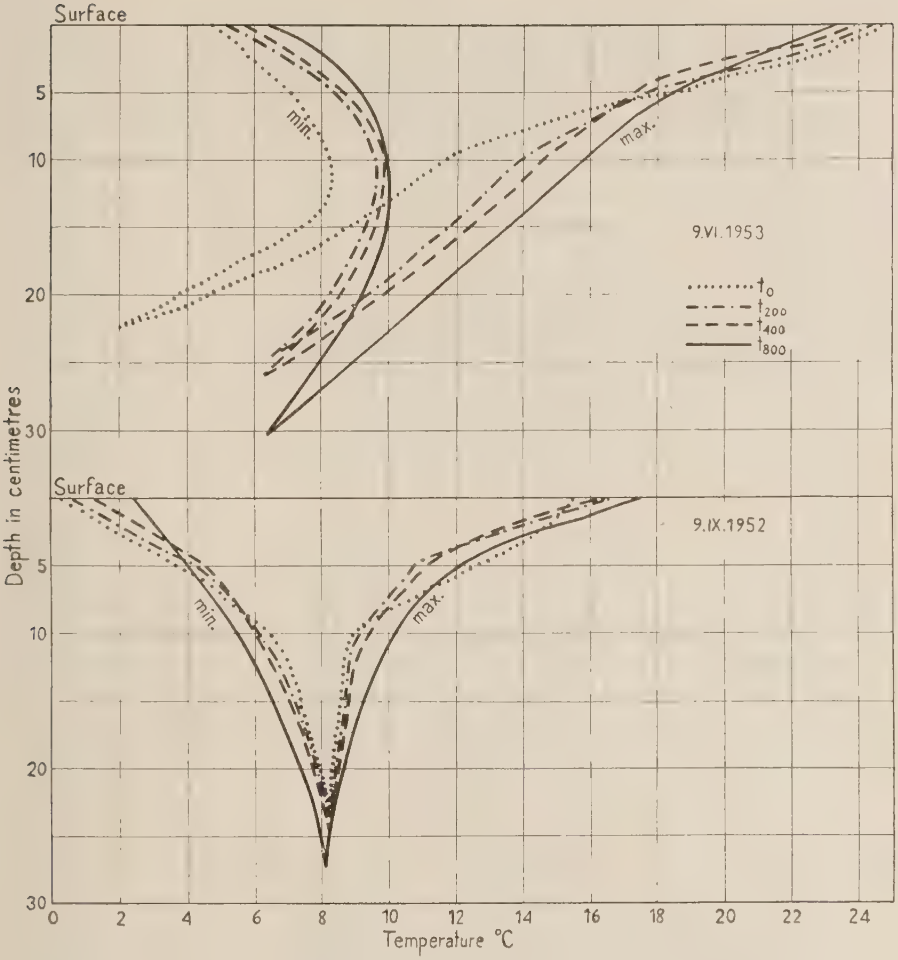

Fig. 20. Range of variation of the temperature in the soil on 9. IX. 1952 and 9. VI. 1953.

Fig. 20 shows the daily variation of the soil temperature on two days. It is seen that the daily variation includes the deeper soil layers in the degree to which mineral soil has been added to the cultivated layer (cf. HOMÉN 1897). It is further seen that at 20 cm depth the amplitude of variation of the temperature is higher where the addition of mineral soil has been greater. At 5 cm depth ,on the other hand, the widest daily variation of the temperature occurs in plot 0. No regularity is observable in the behaviour on the other test plots at this depth. The daily variation of the temperature of the soil surface on 9. VI. 1953 increased with decreasing amount of added mineral soil, the extremes on the different test plots

Table 26. Temperatures of the soil surface, °C (± = variation range)

Test plot	Wet soil surface						Dry soil surface				
	9. IX. 1952		5. V. 1953		25. V. 1953	1. VI. 1953	5. VI. 1953	22. V. 1954		23. VIII. 1954	
	8^h	14^h	8^h	14^h	8^h	8^h	8^h	8^h	20^h	8^h	14^h
0	5.0 ± 0.3	15.5 ± 0.5	7.1 ± 0.4	12.0 ± 0.5	6.9 ± 0.3	16.2 ± 0.5	21.2 ± 0.5	18.1 ± 0.2	11.3 ± 0.2	19.6 ± 0.3	22.4 ± 0.5
200	6.0 ± 0.2	16.6 ± 0.4	7.2 ± 0.2	13.4 ± 0.6	7.0 ± 0.2	16.5 ± 0.4	18.0 ± 0.6	16.0 ± 0.3	10.7 ± 0.3	20.7 ± 0.4	22.2 ± 0.6
400	6.6 ± 0.3	16.6 ± 0.5	7.5 ± 0.4	14.3 ± 0.4	7.5 ± 0.2	17.7 ± 0.2	18.0 ± 0.3	16.4 ± 0.5	9.6 ± 0.2	19.1 ± 0.5	23.1 ± 0.6
800	7.1 ± 0.2	17.8 ± 0.4	7.7 ± 0.3	15.9 ± 0.7	8.7 ± 0.3	17.6 ± 0.4	17.9 ± 0.3	13.4 ± 0.4	8.2 ± 0.2	16.0 ± 0.2	20.4 ± 0.3

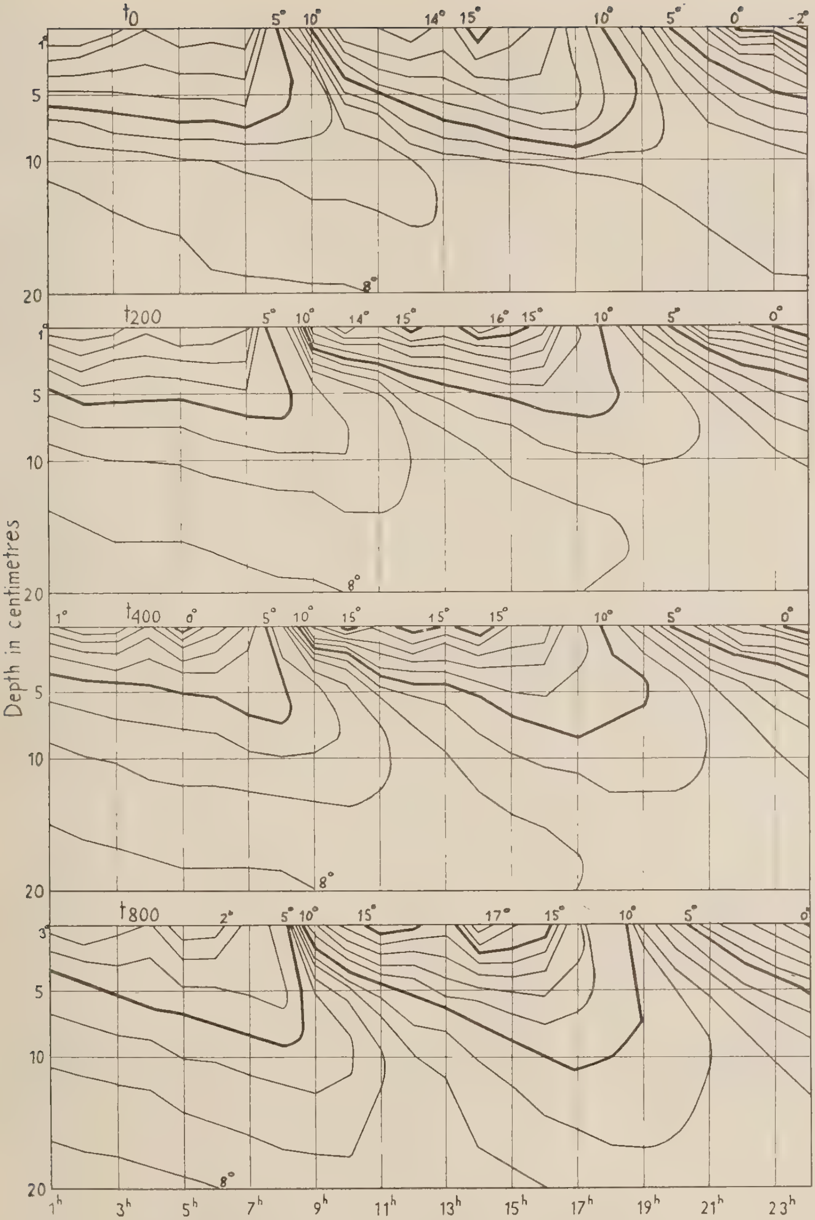

Fig. 21. Variation of the temperature in the soil on 9. IX. 1952 on the different test plots.

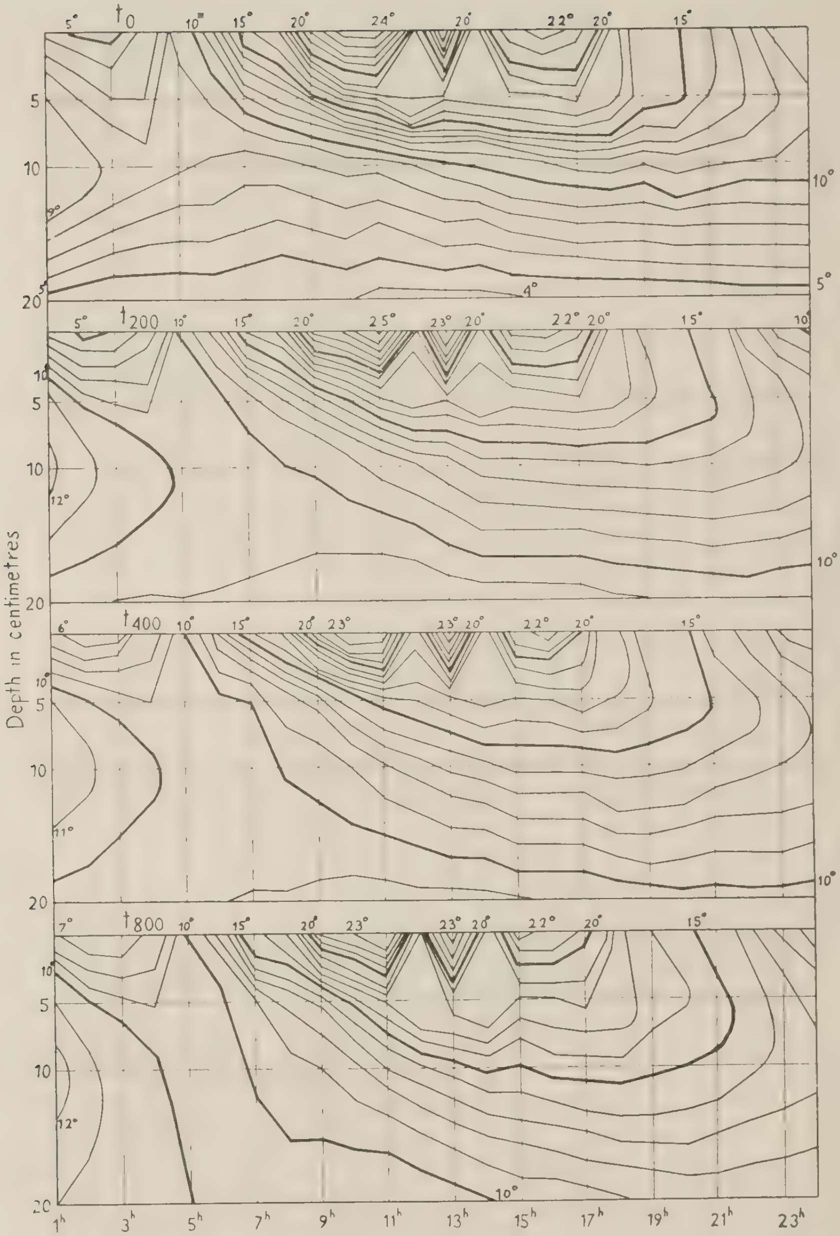

Fig. 22. Variation of the temperature in the soil on 9. VI. 1953 on the different test plots.

assuming a regular order according to the addition of mineral soil. However, the maximum temperature values on 9. IX. 1952 did not conform to the same rule as those on 9. VI. 1952. This finds its explanation in the fact that the soil surface was dry on 9. VI, but wet on 9. IX.

Indeed, the greatest influence on the daytime temperatures of the soil surface seems to be the moisture of the surface. Table 26 contains data on temperature measurements, in connection with which it was possible to determine that the soil surface was completely dry or distinctly wet. The table reveals that in the case of a wet surface the temperature was higher in proportion to the amount of mineral soil added. With a dry soil surface the inverse relation applies.

There are three factors principally responsible for this phenomenon, namely, the different water-retaining capacity of the soil, the difference in thermal conductivity, and the difference in colour of the soil surface. When the soil surface is dry, only little evaporation takes place on any one of the test plots. As peat absorbs more thermal radiation than the improved test plots, which are lighter in colour (fig. 26), and since the rate of thermal flow is lower in plot 0 on account of the lower thermal conductivity of its soil (table 29), it is readily understandable why the temperature of the soil surface on plot 0 is higher than elsewhere in the case of a dry soil surface. When the soil is wet, the higher evaporation on plot 0 (Seyfert 1891) binds a higher quantity of heat and causes the surface temperature to remain below that of the improved test plots. The evaporation is higher on plot 0, since the soil absorbs more thermal radiation (fig. 26) and because the field capacity of the peat is higher than that of peat admixed with mineral soil (Feustel 1936, p. 10).

Two more figures, figs. 21 and 22, describe the daily variation of the temperature on the different test plots. In these figures the same isotherms have been plotted as occur in fig. 20.

In addition to showing the daily changes of temperature, figs. 20, 21 and 22 also reveal the fact which was already established in the preceding section, namely, that in the early summer a higher temperature prevails continously at 20 cm depth in the plots with mineral soil addition than in plot 0. No such temperature differences are observable in September.

6. *On the minimum air temperatures within the plant cover*

During the growing season of 1951 measurements of the air temperature within the plant cover were made in connection with the soil improvement test established at this time. Since the minimum air temperature is of great practical significance in the cultivation of plants susceptible to frost,

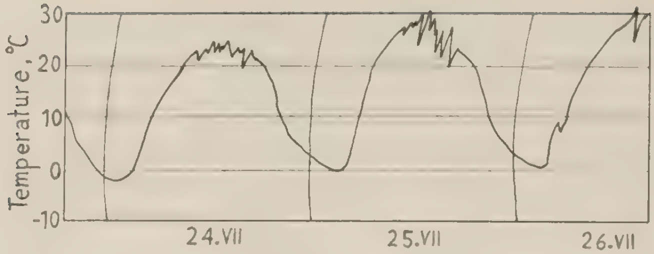

Fig. 23. Record of thermograph placed at the upper limit of the plant cover.

attention was mainly devoted to this aspect of the question. The minimum temperature was also considered as giving a fairly reliable picture of the thermal conditions, since on clear nights, particularly, the change of temperature is smooth (fig. 23) without abrupt variations. With regard to the maximum temperature, on the other hand, it has to be noted that this is a comparatively transient value and thus also reflects the thermal conditions in a rather unsatisfactory way (see e. g. fig. 23). It was actually verified, with the aid of a few series of measurements with three replicates, that the maximum temperatures did not display the same regularity as did the minimum temperatures. Since, moreover, the maximum temperatures are without any practical significance in Finnish conditions, their recording was abandoned. The thermometers used in these measurements were so slow to respond that they could not register the microvariations of the air temperature (FRANSSILA 1949, p. 93–96; GEIGER 1950, p. 57). The transient character of the maximum temperatures in fig. 23 is caused by the rapidly changing cloudiness.

Clear weather being characterized by thermal conditions with wide extremes (FRANSSILA 1949, p. 91) when any possible temperature differences between the test plots will also be most obvious, only minimum temperature values relating to clear days will be presented here.

The temperature measurements within the plant cover were carried out at the level of its upper limit. When the soil surface was bare, the thermometers were placed at 10 cm height. Later in the summer, measurements were also performed within the plant cover, close to the soil surface.

Since in 1951 minimum thermometers were not available in sufficient numbers to furnish replicates to all test plots, the procedure was to use three replicates on two test plots and only one thermometer on the other plots. On different nights the replicates were changed from one plot to another. The variatio range has been recorded after the temperature reading. Furthermore, in those cases where only one thermometer was available, it was moved to different points on the test plot on consecutive nights. This

Table 27. Minimum air temperatures on frosty nights in 1951, °C ($\pm$ = variation range).

Date	Test plot			
	0	200	400	800
12. V	—1.3 ± 0.2	—0.3	0.1	0.2 ± 0.1
14.	—0.5 ± 0.1	—0.4	—0.4	—0.4 ± 0.1
15.	—4.8 ± 0.2	—4.6	—3.4	—3.4 ± 0.2
16.	—4.8 ± 0.2	—4.6	—4.1	—4.1 ± 0.2
17.	—4.5 ± 0.1	—4.2 ± 0.2	—4.0	—3.7
18.	—3.1 ± 0.2	—3.0 ± 0.2	—2.6	—2.4
20.	—4.8	—4.5	—4.3 ± 0.2	—4.0 ± 0.1
21.	—5.4	—4.9	—4.6 ± 0.1	—4.0 ± 0.2
22.	—6.9	—5.5 ± 0.2	—5.1 ± 0.2	—3.9
25.	—0.7	—0.5 ± 0.2	—0.6 ± 0.2	—0.5
26.	—7.0 ± 0.2	—5.6	—5.2	—5.2 ± 0.2
28.	—3.6	—3.4	—3.3	—3.3
30.	—0.2	0.0	—0.1	—0.1
31.	—3.2	—2.7	—2.5	—3.0
Mean...........	—3.6	—3.2	—2.9	—2.7
1. VI	—4.6	—3.8	—3.2	—2.6
4.	—4.4	—3.4	—2.8	—2.1
6.	—1.9	—1.7	—1.4	—1.4
7.	—2.8	—2.1	—2.2	—2.1
8.	—6.0 ± 0.2	—4.7	—4.5	—4.0 ± 0.2
9.	—7.0 ± 0.2	—5.2	—5.0 ± 0.2	—3.8
13.	—8.3 ± 0.2	—6.0	—5.8	—5.0 ± 0.3
18.	—1.0	—0.5	—0.5	0.2
21.	—1.2	—0.1	—0.1	0.5
23.	—2.2	—0.8	—0.2	0.4
Mean...........	—3.9	—2.7	—2.6	—2.0

measure was adopted in order to compensate to some extent for the lack of replicates.

It is seen from table 27 and fig. 24 that distinct differences in temperature occur between the test plots in May and June. These differences in temperature are higher than those observed by Feilitzen (1912 a), Kreutz (1943) and Baden (1952, p. 184). According to table 28 no regular temperature differences exist at the upper limit of the plant cover, or close to the soil surface, later in the summer when the plant cover has reached its full density.

The means of the minimum temperatures of May do not show equally large deviations from each other as those of June (fig. 24). It can be considered one of the reasons for this phenomenon that the temperature differences in the soil between the test plots are higher in May (fig. 13). The highest temperature differences between plot 0 and the other test plots occurred on the night of 12—13. VI. It is seen from table 27 that on this night replicates were in use on plot 0 and on plot 800, so that at least the

differences in temperature between these two plots can be considered as having actual significance. Even the minimum temperatures of plots 200 and 400 can be considered representative within an accuracy of 0.5 C, since the replicates have seldom shown greater discrepancies.

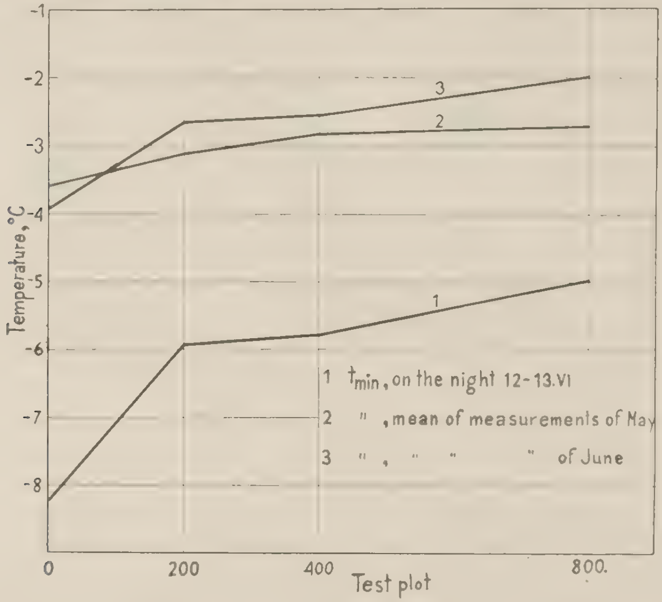

Fig. 24. Minimum temperatures in 1951 at top height of the shoots.

It is further evident from fig. 25 what practical significance the differences in minimum temperature in the spring have had. The curve in this figure shows the number of frost-damaged shoots from surfaces of equal area throughout the spring. The bulk of the damage was caused by the night of 12–13. VI. On plot 0 the damage would probably have been even greater if the plants on this plot had completely tillered before this date. Table 2 shows that complete tillering did not obtain until about two days later.

Table 28. Minimum air temperatures in 1951, C ($\pm$ — variation range).

Date	At the height of the plant tops				At 10 cm height from the soil surface			
	0	200	400	800	0	200	400	800
1. VIII	—1.0 ± 0.3	—1.0 ± 0.2	—1.2 ± 0.1	—0.8 ± 0.2	1.0 ± 0.2	1.0 ± 0.2	1.2 ± 0.2	1.2 ± 0.2
5. VIII	2.2 ± 0.2	2.4 ± 0.3	2.2 ± 0.2	2.4 ± 0.3	4.0 ± 0.1	4.1 ± 0.3	4.2 ± 0.1	4.1 ± 0.4
9. IX	—2.0 ± 0.2	—1.8 ± 0.2	—1.8 ± 0.3	—2.0 ± 0.2	—1.0 ± 0.3	—1.2 ± 0.1	—0.9 ± 0.3	—1.0 ± 0.2
10. IX	—2.2 ± 0.3	—2.1 ± 0.3	—2.2 ± 0.3	—2.2 ± 0.2	—1.1 ± 0.2	—1.4 ± 0.2	—1.2 ± 0.4	—1.0 ± 0.3

The soil temperature differences between the test plots in August and September were small (fig. 13). Furthermore at this stage the plant cover impedes the heat exchange between soil and air to its fullest capacity. It is thus quite plausible that no greater differences in minimum temperature occur in the air within the plant cover at this time.

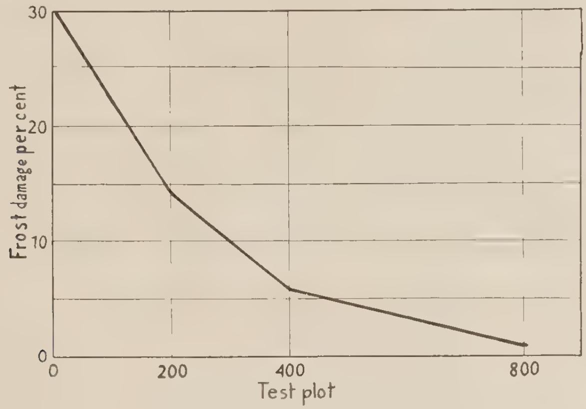

Fig. 25. Frost damage on the different test plots in the spring of 1951.

7. *On the causes of the different thermal conditions*

The most important thing, from the practical point of view, is to know what kind of result will be obtained when mineral soil is added to the soil of peat land. In this sense the causes underlying the change in thermal conditions are without significance. However, this question has its own particular interest. It will also be easier to interpret the results described above, if it is possible to analyze the factors affecting the thermal conditions in the soil. A detailed study of the question would require the performance of thorough investigations on the heat economy of the different test plots. This was not possible in the present instance, since the evaporation from the soil surface could not be determined. To the best of the author's knowledge no method suitable for this purpose has as yet been discovered. However, some factors influencing the conditions in question were investigated.

a. Radiation balance

It is obvious that the radiation balance will be essentially different on the different test plots only so long as the vegetation does not cover the soil completely, assuming that no temperature differences occur in the

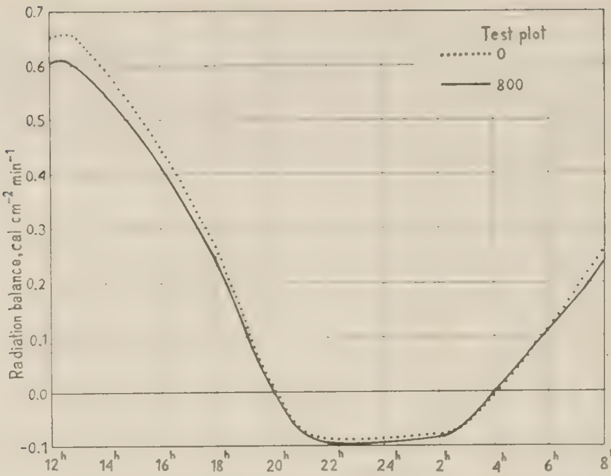

Fig. 26. Radiation balance on 27—28. V. 1954.

plant cover. After the plant cover has reached full density it rather than the soil surface determines the radiation balance.

Fig. 26 shows the radiation balance of plot 0 and of plot 800 on 27—28. V. 1954. The wind velocity was low throughout the 24 hours, at the time of measurement not more than 2 m/sec. Thus no disturbing influence of the lateral wind upon the instrument could occur (Suomi 1954, p. 279). It is seen from the figure that plot 0 absorbs more solar radiation during the daytime than the soil of plot 800 and that its effective outgoing radiation in the night is lower than that of plot 800. The radiation balance curves of the other test plots lie regularly between these two curves, but for the sake of clarity they have been omitted in the figure. Numerous separate series of measurements gave results similar to those shown in fig. 26.

The higher heat energy absoption of plot 0 during the daytime is probably caused by the differences in the colour of the soil surface, the mineral soil employed being of light colour. For this reason the plots admixed with mineral soil reflected a greater fraction of the incoming radiation. The higher temperature of plot 0 in the daytime (2.5 C higher at 14 hrs.) has been unable to increase the outgoing radiation sufficiently to compensate for the difference in reflection. The lower effective outgoing radiation from plot 0 in the night as compared with test plot 800 possibly finds its explanation in the lower soil surface temperature which obtains at night on the plot 0. At 23.50 the temperature on the soil surface was 5.7 C on plot 0 and 7.0°C on plot 800, the corresponding values at 1.50 after midnight being 2.2 C and 3.6 C. The influence of differences in the colour of the soil surface upon soil temperature has been investigated by Karsten

(1916); he found that a soil surface covered with coal has a lower temperature at night than a surface covered with sand. On the other hand, at 1 cm distance from the soil surface he noticed a lower temperature over a surface covered with chalk, both in the daytime and at night, than over a coal-covered surface. In the daytime the difference amounted to 10°C. In these cases the different utilization of the thermal radiation may have been of significance. The fact that the chalk-covered surface did not display a higher temperature at night than that covered with coal can probably be attributed to the fact that the soil covered with coal has absorbed so much more thermal energy during the daytime as to store a heat quantity easily sufficient to compensate for the possibly somewhat higher outgoing radiation during the night. The high temperature difference at 1 cm depth seems to indicate this condition. Bouyoucus (1913, pp. 30—33) found color to have little or no effect on radiation, but quite an appreciable affect on absorption.

Kirchhoff's fundamental researches have shown that the total radiant energy given off by a body is highly dependent on its absolute temperature. If the amount of outgoing radiation is calculated for plot 0 and for test plot 800 from the Stefan-Boltzmann formula

$$S = \sigma T^4,$$

where σ = constant (which in this case is assumed to equal that pertaining to an absolutely black body) and T = absolute temperature, and the difference in outgoing radiation between the two plots is determined, the round result is 0.01 cal/cm^2 min, which is in fairly good agreement with the curves of fig. 27.

The difference in the radiation balance also throws some light upon the question of why the mean temperature differences between the test plots at 5 cm depth do not appear distinctly when the soil surface is bare of vegetation (fig. 13). In this case plot 0 is capable of absorbing more thermal energy than the other plots, but gives off less radiation in the night. When the soil surface is shaded by the plant cover, the amount of radiation indicent on the soil surface is less and the differences in radiation balance can no longer play such an important role. On the basis of the foregoing the dark colour of the peat can be considered advantageous from the standpoint of heat economy.

b. Thermal conductivity of the cultivated layer

The thermal conductivity has been calculated from the formula

$$\lambda = \varsigma c K$$

where λ = thermal conductivity, ς = density, c = specific heat per unit of weight and K = thermal diffusivity. Two formulae have been developed for the determination of the thermal diffusivity from the formulae in page 56, one of them being based upon the varying amplitudes found at different depths, the other on the time lag of the extreme values with increasing depth. These equations are

$$K_a = \frac{\pi \cdot x^2 \cdot \log^2 e}{T \cdot (\log A_1 - \log A_2)^2}$$

$$K_r = \frac{\pi \cdot x^2}{T \cdot r^2 \cdot \sin^2 1}$$

where K_a = thermal diffusivity as calculated on the basis of the amplitudes, K_r = thermal diffusivity as calculated on the basis of the time lag of the extremes, x = distance in depth between the layers under consideration, e = base of the natural logarithms, T = period length of the curve, A_1 and A_2 = amplitudes at the given depths, and r = time lag of the occurrence of the extremes, expressed in angular units.

The method is inaccurate when applied to two dissimilar soil layers. The daily variation of the temperature at 20 cm depth at the test plots, however, is small. From this it follows that the values of K calculated from these formulae are usefull to indicate the differences between the test plots.

Fig. 27 shows the calculated values of the specific heat at the moisture contents 50 % and 100 % saturation. It is seen that the specific heat per unit of volume of completely dry soil, varies between 0.07—0.17 cal cm^3 · °C. If the estimated specific heat values of peat and dry mineral

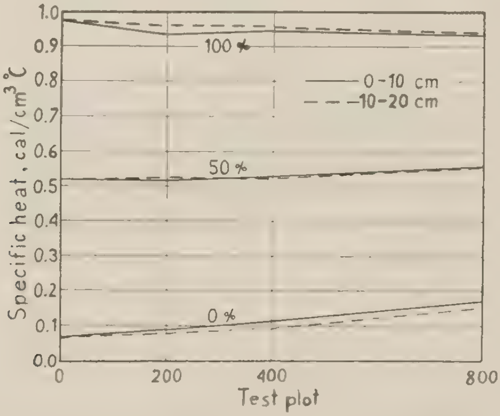

Fig. 27. Specific heat, on a volume basis, of the cultivated layer on the different test plots.

Table 29. Thermal diffusivity (K_a) and thermal conductivity cal/cm · sec · °C (λ) of the cultivated layer at the depths 0—10 cm and 0—20 cm. Average moisture in the 0—20 cm layer on 9. IX. 1952 and 9. VI. 1953: 80.5 % and 58.4 % of saturation moisture, respectively.

Layer	Test plot	9. IX. 1952		9. VI. 1953		Mean	Mean
		K_a	λ	K_a	λ	K_a	λ
0—10 cm ...	0	0.00116	0.00090	0.00117	0.00072	0.00117	0.00081
	200	0.00122	0.00107	0.00167	0.00108	0.00145	0.00108
	400	0.00158	0.00131	0.00197	0.00122	0.00178	0.00127
	800	0.00223	0.00182	0.00292	0.00183	0.00258	0.00175
0—20 cm ...	0	0.00122	0.00098	0.00138	0.00084	0.00130	0.00091
	200	0.00150	0.00125	0.00170	0.00104	0.00160	0.00115
	400	0.00167	0.00141	0.00192	0.00116	0.00180	0.00129
	800	0.00224	0.00184	0.00311	0.00195	0.00268	0.00190

soil err by 10 %, which does not seem possible, this would cause an error of 0.007—0.017 units in the specific heat values. At 50 % saturation the error amounts to 1.3—3.0 % and at saturation moisture to 0.7—1.8 %.

The change in specific heat on addition of mineral soil is due to two causes. First, mineral soil has a different thermal conductivity from peat and secondly the compression of the soil gives rise to changes. The lower specific heat of the 0—10 cm layer in test plot 200 in comparison with plot 400 at saturation is attributable to the lower total porosity, ass will be evident later on.

Table 29 shows the values of thermal diffusivity and thermal conductivity which have been calculated from the figures for two days on which different moisture conditions (cf. SMITH 1939) prevailed in the cultivated layer. The values have been calculated only with the aid of the formula relating to the amplitudes, the observations made every hour proving too few to allow of a sufficiently accurate determination of the times of occurrence of the extremes. In the investigation of KARSTEN (1917, p. 319) the thermal conductivity was 0.00112 on plot 0 and 0.00128 on the test plot with 400m³ sand/ha.

It is evident from the table as well as from fig. 28 that the thermal conductivity increases on an average nearly, but not quite linearly with the addition of mineral soil. Taking into account the fact that compression of the soil also influences its thermal conductivity, a better interpretation of the results is possible, if the total porosity of the cultivated layer in the different test plots is taken into consideration. According to determinations made during the investigations the average total porosity was: 79.0 % on test plot 800, 85.5 % on plot 400, 82.3 % on plot 200 and 88.0 % on plot 0. The compression of the cultivated layer was thus highest on test plot 800,

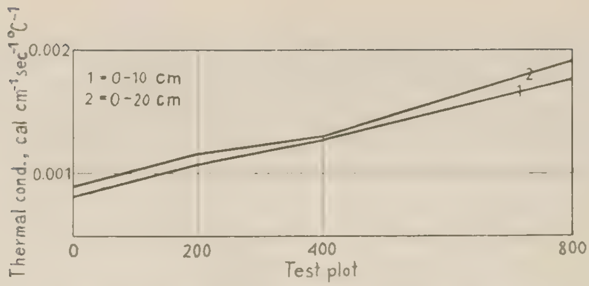

Fig. 28. Thermal conductivity of the cultivated layer on the different test plots.

next highest on plot 200, with plot 400 third, and lowest on plot 0. This explains, among other things, why the thermal conductivity of the 0—20 cm layer in plot 200 experienced a greater improvement (0.00024) in comparison with the thermal conductivity of plot 0 than that of plot 400 in comparison with plot 200 (0.00014). In the 0—10 cm layer the corresponding differences in the same direction are not as clearly visible. KARSTEN (1911, p. 27) and SMITH (1938, p. 18) have found that relating thermal conductivities to corresponding volume weights of the packing, is linear.

Since the compression of the soil was found to differ in the way described above in the different test plots and since there was no reason to suppose that the test plots had been treated in any way differently in the establishment of the test and during its course, a laboratory test was arranged in order to discover whether the cultivated layers of the different test plots might have an inherent natural tendency towards differences in compression. For this purpose samples were taken from the cultivated layer of each test plot. The samples were pulverized and cylindrical vats of 16 cm diameter and 10 cm height were filled with the samples without any compression. The receptacles were dropped three times upon the table from a height of about 3 cm, after which samples were taken and their total porosity was determined. The experiment was carried out in four replications. The results were subjected to analysis of variance and they are shown in table 30.

Table 30. Total porosity of soil samples taken from the cultivated layer, after laboratory treatment.

	Test plot			
	0	200	400	800
Total porosity % ..	90.3	82.8	87.2	79.8

Laest significant difference: .... * 4.07 % F value 29.17*
** 5.08 % m, % 1.6
*** 5.85 %

Table 31. Quantity of heat conducted into the soil, and given off by the soil, during 24 hours (9. VI. 1953).

Test plot	Quantity of heat, cal/cm²		
	Conducted into the soil	Given off by the soil	Difference
0	78.90	72.75	+6.15
200	84.00	77.40	+6.60
400	85.80	79.15	+6.65
800	94.80	87.70	+7.10

It is seen that the compression occurred approximately as it did in nature. The different inherent tendency to compression of plots 200 and 400 may be explained by the fact that test plot 200 is situated in »rimpi» [1]) of the bog and plot 400 on a peat bank, both of these occurring in the bog area in question in equal amounts in its natural state.

A result of the changed thermal conductivity of the cultivated layer is that the heat quantity which travels into the soil by way of conduction and the quantity given off at night vary between the test plots. The said heat quantities and their difference have been calculated for one day (9. VI. 1953) and are shown in table 31. It is seen that the thermal flow into the soil during the day has increased with the amount of added mineral soil, but similarly the outgoing heat at night has increased. Owing to the long duration of the day in question the difference of these heat quantities is positive in this instance. In the investigations of Karsten (1917, p. 238) the heat exchange was also highest in the improved test plots.

The addition of mineral soil thus promotes the warming of the soil during the day, but it also promotes its cooling at night. It is thus easily understood that the addition of mineral soil is better able to increase the mean temperature of the day if the daytime is longer. This explanation likewise makes the considerable influence of the mineral soil in the spring and early summer very understandable. It is also to be expected that the effect of addition of mineral soil in raising the mean temperature of the soil in the spring and early summer will be greater at higher latitudes where the day is longer.

It is appropriate in this connection to return once more to fig. 15. It was seen from this figure that the temperature differences between plots 800 and 0 at 20 cm depth were actually considerably higher in the early summer than those calculated theoretically on the assumption that thermal conductivity is the only point of difference. The cause of this phenomenon was found to be fact that the temperature begins to rise on plot 0 about

[1]) Rimpi = Finnish expression for small bog area, periodically flooded, with mud bottom and more or less poorly developed moss vegetation.

Table 32. Progress of the melting of frozen ground up to 20 cm depth.

Test plot	Year			
	1952	1953	1954	1955
0	17. V	17. V	21. V	4. VI
200	11. V	5. V	15. V	29. V
400	8. V	3. V	15. V	28. V
800	3. V	27. IV	3. V	20. V

3 weeks later than on plot 800. The temperature differences in the autumn are in fairly good agreement with the theoretically calculated values. The difference in thermal conductivity of the soil cannot be the immediate cause of the great differences between the test plots in the spring, but also the different time of thawing of the frozen soil is connected with this question. Not until the ground has thawed to a greater depth than 20 cm can the soil begin to attain higher temperatures at this depth. On plot 0 this stage is achieved some weeks later than on plot 800 (table 32.) It is well-known that frozen peat land thaws at a slower rate than frozen mineral soil (SIMOLA 1926). This fact further substantiates the inference that the significance of addition of mineral soil in the heat economy of peat land is greater in latitudes where the ground freezes to considerable depths and in general in conditions where freezing of the ground occurs.

It was further seen from fig. 15 that the rise of temperature on plot 0 took place at nearly the same rate as on plot 800 as soon as the soil started to increase considerably in temperature. For this observation the explanation can be advanced that although the cultivated layer of plot 0 is of lower thermal conductivity than that of plot 800, the temperature gradient in the cultivated layer is at the same time higher than in plot 800. For it should be remembered that the thermal flow (Q) is dependent, not only on the thermal conductivity (λ), but also on the temperature gradient ($\frac{t_2-t_1}{x}$), according to the equation

$$Q = \frac{\lambda\ (t_2-t_1)}{x}$$

c. Evaporation

It has already been pointed out that the evaporation of water from the soil surface was not accessible to measurement. It is, however, a generally accepted opinion that the evaporation of water, and thus also the amount of heat bound by evaporation, is higher on peat land than on mineral soil. Some authors even maintain that the admixture of mineral soil with peat

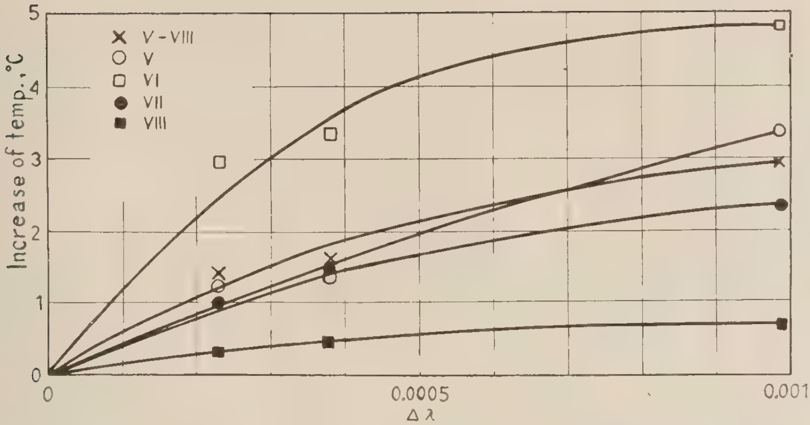

Fig. 29. Increase of mean temperatures at 20 cm depth in comparison with test plot 0 according to two years' observations, in dependence on improvement of thermal conductivity.

should cause a reduction of the evaporation and thus increase the soil temperature. Seyferth (1891) performed evaporation experiments on unsanded and sand-covered areas and areas where the peat was mixed with sand on a bog without vegetation. He determined the evaporation by means of measurements of the rainfall and the quantities of water which flowed off from the region. According to the mean values of three years the quantities of water evaporated were related as (1891, p. 854):

unsanded		admixed with sand		sand-covered
100	:	81	:	37

In his measurements in receptacles he found the following ratios: 100: 67: 23 (1891, p. 861).

Results showing a similar trend have also been obtained by Tacke (1916) and Krüger (1922).

According to these investigations the use of sand, and particularly a sand covering, has a remarkable influence upon evaporation. There is one point also in the present investigation which seems to indicate that evaporation was highest in plot 0, at least when the soil surface was clearly wet. It was seen from table 26 that the temperature on the soil surface is lowest on plot 0 in the daytime when evaporation occurs in considerable amounts. The significance of evaporation with regard to the heat economy of the soil is probably also evident from the mean temperatures. It was already seen in the foregoing that the thermal conductivity of the cultivated layer in plot 200 was nearer to that of plot 400 than to that of plot 0. On

the other hand, it is also indirectly evident from figs. 13 and 14 that the mean temperature of the soil in the summer months increased initially at quite a rapid rate with the addition of mineral soil, its increase being less pronounced later. This is unlikely to be the result of an improvement in thermal conductivity alone (fig. 29), but probably the reduced evaporation also contributes to this increase of the mean temperatures. It is obviously true that the reduction of evaporation is of nearly the same magnitude in all test plots with added mineral soil, which would explain why even the admixture of a small quantity of mineral soil has a relatively good influence upon the heat economy of the soil in comparison with greater quantities. The significance of evaporation with regard to the heat economy of the soil has been remarkable during the years under investigation for the very reason that the moisture content of the soil has almost continuously been relatively high, owing to the frequency of rainy days (table 3).

Summary

The purpose of the present work was to determine the degree to which the admixture of mineral soil with the cultivated layer of poorly humified, newly reclaimed peat land is able to influence the thermal conditions of the soil. The investigations were carried out during the years 1951—1955 at Pelsonsuo ($\lambda = 26.5°E$, $\varphi = 64.3°N$). The treatments consisted of the admixture of 0, 200, 400 and 800 m^3 of mineral soil per hectare, respectively. A study has also been made of the causes which produce these changes in thermal conditions. The most essential results of this investigation are:

1. The addition of mineral soil increases the mean temperature of the soil throughout nearly the whole growing season and lowers it at other times of the year. The greatest temperature differences between the test plots occur in the spring and early summer.

2. The temperature differences between the different test plots in the spring and early summer, which considerably exceed the theoretically calculated differences, are caused in part by the slower thawing of the ground in the case of pure peat soil.

3. The greatest temperature differences between the different test plots occur at the lower boundary of the layer to which the mineral soil has been added.

4. The addition of mineral soil to the cultivated layer causes distinct temperature changes even at 100 cm depth.

5. The mean soil temperatures of the months of the growing season display a linear dependence on the amount of mineral soil added when the latter is plotted according to a geometric succession with the basis 200 m^3/ha and with the ratio 3/2.

6. The daily range of variation of the temperature at depths equal to or greater than 10 cm increases in proportion to the amount of mineral soil added. In the layer above 10 cm depth the amplitude on the plot without added mineral soil is as a rule the largest. The amplitude of the temperature at the soil surface is dependent on its moisture condition. On a dry soil surface the amplitude is greatest on the test plot without mineral soil, whereas no noteworthy differences occur in any other case.

7. The addition of mineral soil causes an increase of the minimum temperatures of the air layer adjacent to the soil surface in the spring.

Later in the summer no differences in minimum temperature occur in the air within the plant cover.

8. It is due to the addition of mineral soil that the radiation balance is always lower on the test plots with mineral soil addition than on the untreated plot as long as the plant cover does not shade the soil surface.

9. The improvement of the thermal conductivity of the cultivated layer by different additions of mineral soil is approximately linear.

10. The comparatively great increase of the mean temperatures in comparison with the untreated plot which is caused by small additions of mineral soil cannot be explained merely on the basis of the improved thermal conductivity of the soil. Probably it is caused in part by the reduction in evaporation which may possibly be of the same order of magnitude in the case of all test plots with added mineral soil. Thus small additions of mineral soil have a relatively greater effect than large additions.

11. The significance of the admixture of mineral soil upon the thermal conditions of cultivated peat land increases with the likelihood of frozen ground and with the length of the day during the growth period.

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Selostus

Kivennäismaan sekoittamisen vaikutuksesta suoviljelyksen lämpöoloihin

YRJÖ PESSI

Hallakoeasema, Pelsonsuo

Tutkimuksen tarkoituksena on ollut selvitellä, millä tavoin kivennäismaan sekoittaminen vähänmaatuneen uudisviljelyssuon muokkauskerrokseen vaikuttaa maan ja maan pinnan läheisen ilmakerroksen lämpöoloihin.

Tutkimukset on suoritettu Pelsonsuolla ($\lambda = 26.5°$E. v. G. $\varphi = 64.3°$) vuosina 1951—1955 kahden maanparannusainekokeen yhteydessä. Koejäseninä olivat 0-ruutu, jolla kivennäismaata ei käytetty, sekä ruudut, joiden muokkauskerrokseen sekoitettiin 200, 400 ja 800 m³ Ht/ha. Turvekerroksen paksuus oli ensimmäisessä kokeessa 60 cm (saraturvetta) ja toisessa kokeessa 156 cm (0—100 cm saraturvetta, 100—156 cm ruskosammalsaraturvetta). Maan lämpötilamittaukset suoritettiin termoelementeillä ympäri vuoden muutamien vuorokausien väliajoin. Vuorokautisina havaintoaikoina olivat kesäkuukausina klo 8, 14 ja 20, talvikuukausina suoritettiin mittauksia vain kerran vuorokaudessa. Vuosina 1951—1953 oli koekasvina kaura, vuonna 1954 mittaukset tapahtuivat maan pinnan ollessa paljaana.

Ilman lämpötila mitattiin alkoholialinarvomittareilla. Huomio kiinnitettiin lähinnä minimilämpötiloihin. Nämä mittaukset tapahtuivat keväisin oraiden latvojen korkeudella. Myöhemmin kesällä suoritettiin muutamia mittaussarjoja viljan ylärajassa sekä lähellä maan pintaa.

Tutkimusten yhteydessä tehtiin havaintoja lumipeitteen syvyydestä ja tiheydestä. Lisäksi seurattiin pohjaveden pinnan etäisyyden vaihteluja maan pinnasta lukien samoin kuin roudan sulamista eri koeruuduilla.

Tutkimuksessa on pääasiallinen huomio kiinnitetty maassa eri koeruutujen kesken vuoden eri ajankohtina vallitseviin lämpötilaeroihin. Havaintoaineiston perusteella on laskettu havaintovuorokausien keskilämpötilat kesäkuukausina sekä kuukausien keskilämpötilat. Muutamia mittaussarjoja on suoritettu myös tunneittain ympäri vuorokauden vuorokautisten lämpötilavaihtelujen selvittämiseksi. Samoin on muutamin mittaussarjoin seurattu maan pinnan lämpötiloja sekä säteilytasetta eri koeruuduilla.

Havaintoaineiston perusteella on eritelty niitä syitä, jotka vaikuttavat maan lämpötalouteen eri koeruuduilla. Tässä tarkoituksessa on laskettu muokkauskerroksen lämmönjohtokyky sen kahdessa erilaisessa kosteustilassa. Teoreettisesti laskettujen ja kokeellisesti saatujen lämpötilakäyrien eroavuus ilmentää lähinnä roudan vaikutusta maan lämpöoloihin alkukesällä. Haihtumisen osuutta maan lämpötalouteen on tarkasteltu kirjallisuudessa esiintyvien tietojen perusteella.

Tärkeimmät tutkimustulokset ovat seuraavat:

1. Kivennäismaan lisäys kohottaa maan keskilämpötilaa lähes koko kasvukauden ajan ja alentaa sitä muulloin. Suurimmat lämpötilaerot esiintyvät eri koeruutujen kesken keväällä ja alkukesällä (taulukot 9—21, kuvat 13, 14, 16—19).

2. Kevään ja alkukesän teoreettisesti laskettuja lämpötilaeroja huomattavasti suuremmat todelliset lämpötilaerot eri koeruutujen kesken johtuivat pääasiassa roudan hitaammasta sulamisesta parantamattomassa turpeessa (taulukot 23 ja 32, kuva 15).

3. Suurimmat kesäkuukausien aikaiset eri koeruutujen keskiset lämpötilaerot esiintyvät sen kerroksen alarajassa, mihin kivennäismaa on sekoitettu (taulukot 10, 14, 15, 18—21, 23, kuvat 13, 14, 17, 19).

4. Kivennäismaan sekoittaminen muokkauskerrokseen aiheuttaa lämpötilan muutoksia vielä 100 cm:n syvyydessäkin (taulukot 9—21, kuvat 13, 17—19).

5. Kasvukauden kuukausien maan keskilämpötilat kohoavat suoraviivaisesti lisätyn kivennäismaamäärän funktiona geometrisen sarjan mukaan, jonka kantalukuna on 200 (m^3 kiv. maata/ha) ja suhdelukuna 3/2 (kuva 16).

6. Vuorokautinen lämpötilan amplitudi on 10 cm:n syvyydestä lähtien alaspäin sitä suurempi, mitä enemmän turpeeseen on lisätty kivennäismaata. 10 cm:n syvyydestä ylöspäin lämpötilan amplitudi on suurin yleensä 0-ruudulla. Maan pinnan lämpötilan amplitudi riippuu vallitsevasta kosteudesta. Maan pinnan ollessa kuiva on amplitudi suurin 0-ruudulla, muulloin ei eroja sanottavasti havaittu (taulukko 26, kuvat 20—22).

7. Kivennäismaan lisäys vaikuttaa keväisin maan pinnan läheisen ilmakerroksen minimilämpötiloja kohottaen. Minimilämpötilaeroja ei havaittu myöhemmin kesällä kasviston ilmastossa (taulukot 27 ja 28, kuvat 24 ja 25).

8. Kivennäismaan lisäyksestä johtuu, että säteilytase on kivennäismaata saaneilla ruuduilla aina pienempi kuin 0-ruudulla niin kauan kuin kasvipeite ei varjosta (kuva 26).

9. Muokkauskerroksen lämmönjohtokyky paranee jokseenkin suoraviivaisesti kivennäismaata lisättäessä (taulukko 29, kuva 28).

10. Pienempien kivennäismaamäärien aiheuttama verraten jyrkkä keskilämpötilojen nousu 0-ruutuun verrattuna ei ole selitettävissä yksinomaan maan lämmönjohtokyvyn paranemisen perusteella. Todennäköisesti nousu johtuu osaltaan haihtumisen pienenemisestä, mikä kaikilla kivennäismaata saaneilla ruuduilla voi olla samaa suuruusluokkaa. Näin ollen pienet kivennäismaamäärät vaikuttavat suhteellisesti paremmin kuin suuret (vrt. kuva 29).

11. Kivennäismaan sekoittamisen vaikutus kasvukauden aikaisiin suoviljelyksen lämpöoloihin on sitä suurempi, mitä runsaammin routaa esiintyy ja mitä pitempi on päivä kasvukauden aikana.